Dark Matter: Looking for WIMPs in the Galactic Halo

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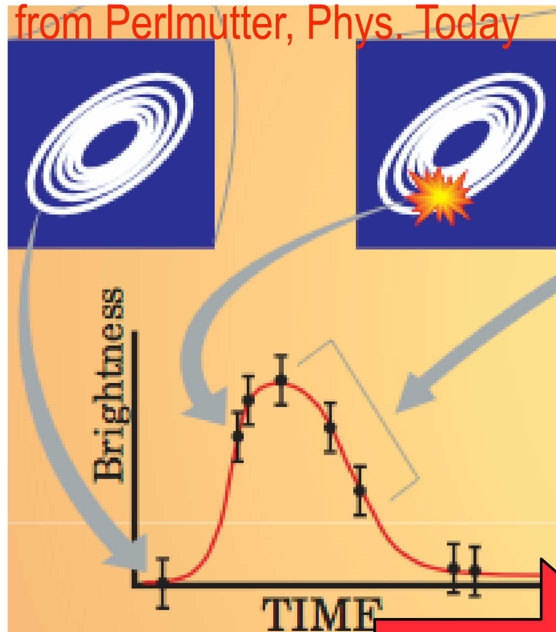
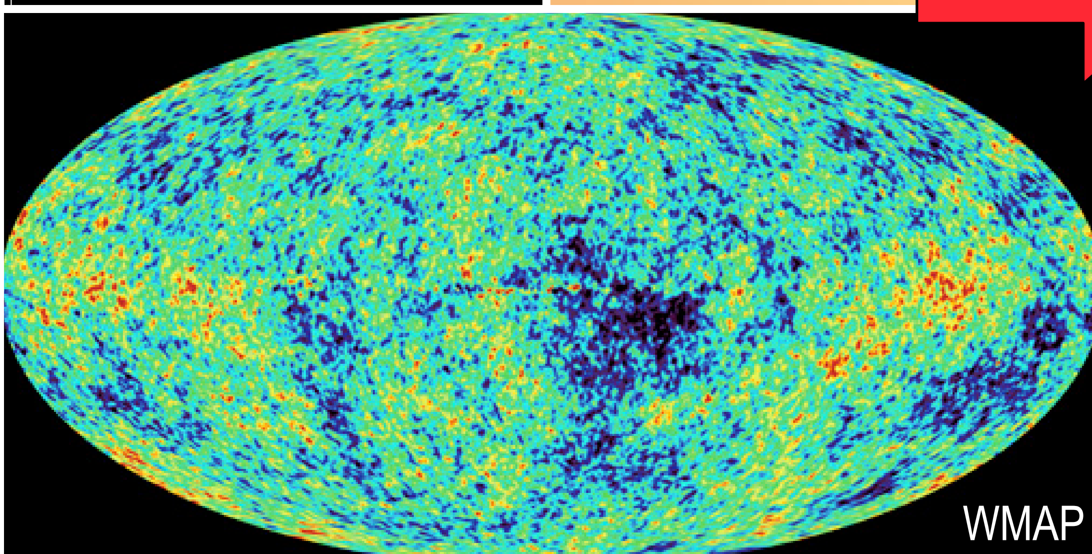
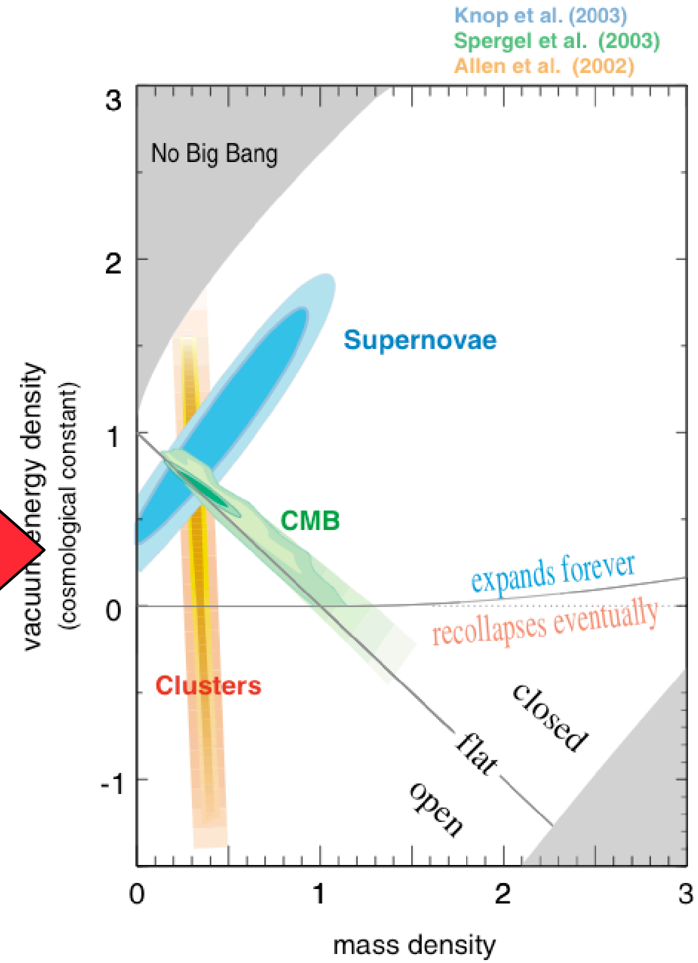
Case Western Reserve University
CDMS Collaboration

PANIC
27 October 2005

Standard Cosmology



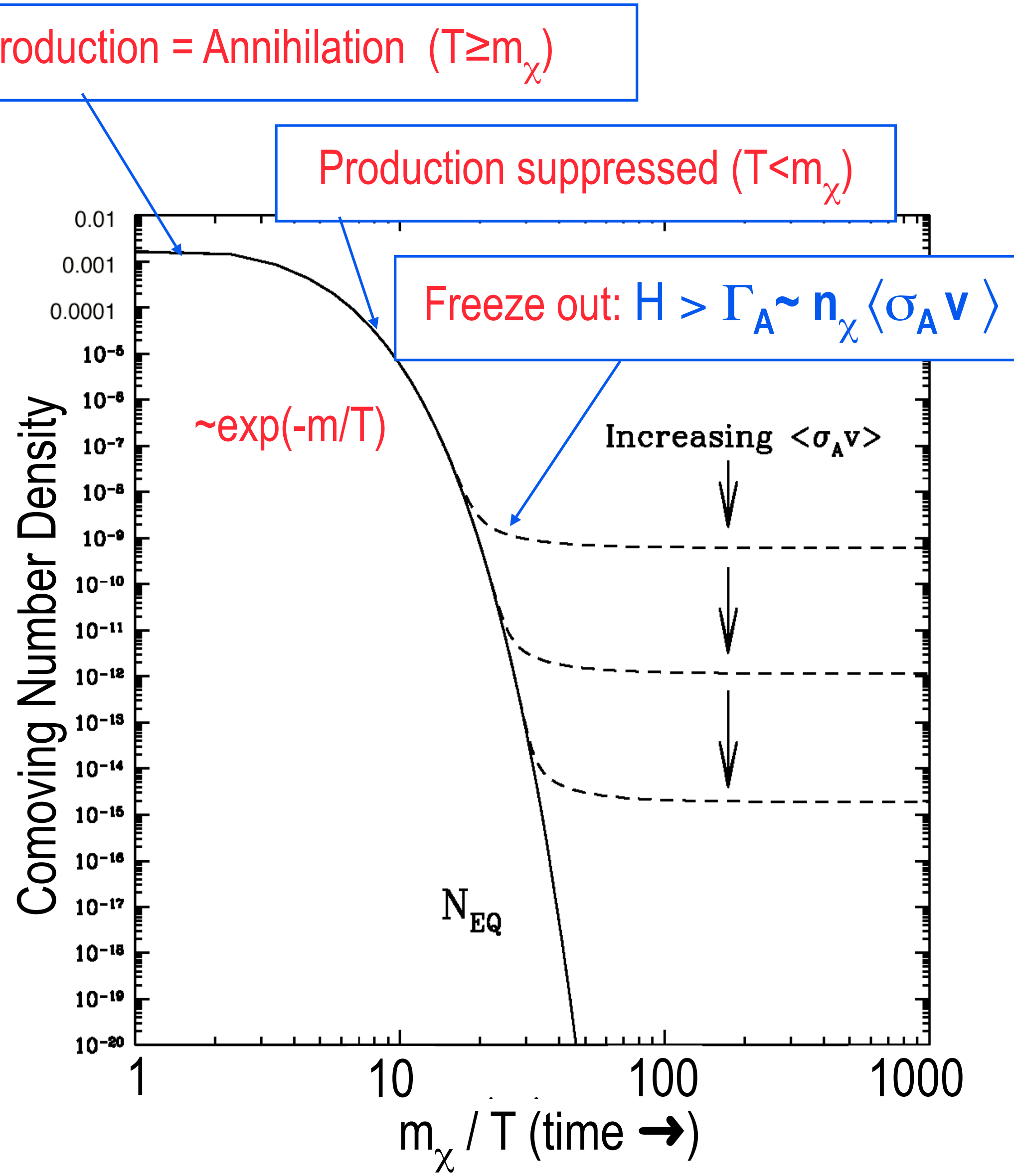




Non-Baryonic Dark Matter

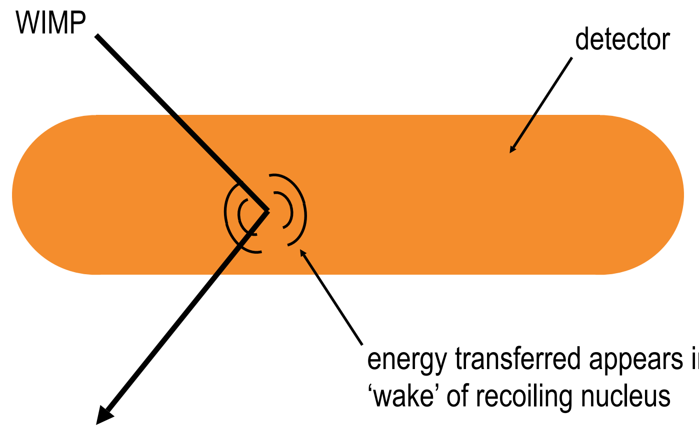
- **Matter density**
  - $\Omega_{Matter} = 0.30 \pm 0.04$
- **Big Bang Nucleosynthesis**
  - $\Omega_{Baryons} = 0.05 \pm 0.005$
- **Nature of dark matter**
  - **Non-baryonic**
  - **Large scale structure predicts DM is 'cold'**
- **WIMPs – Weakly Interacting Massive Particle**
  - **~10–1000 GeV Thermal relics**
  - $T_{FO} \sim m/20$
  - $\sigma_A \sim$ **electroweak scale**

SUSY/LSP



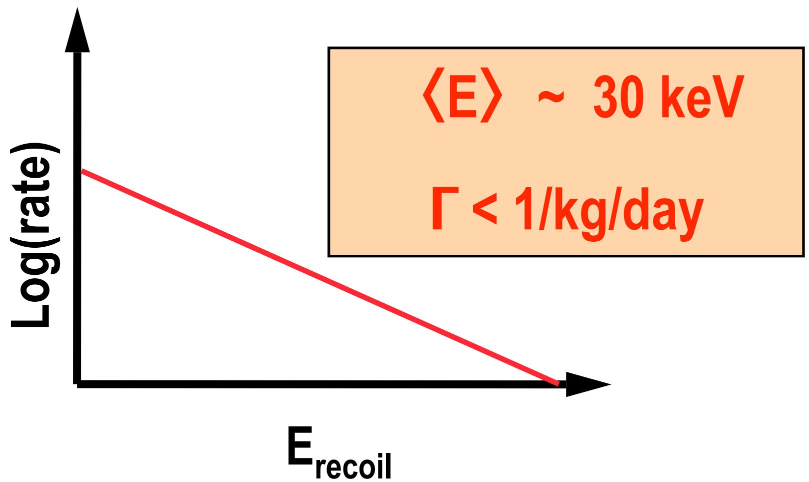
WIMPs in the Galactic Halo

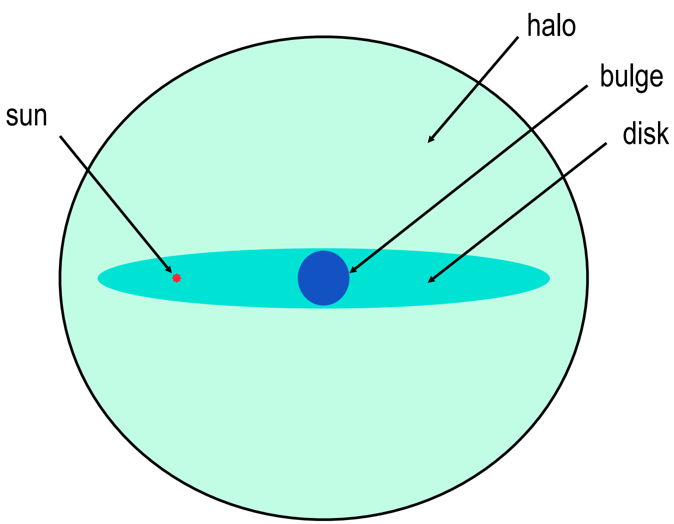
WIMPs – the source of Mass in the Rotation Curves?



WIMP-Nucleus Scattering

Scatter from a Nucleus in a Terrestrial Particle Detector



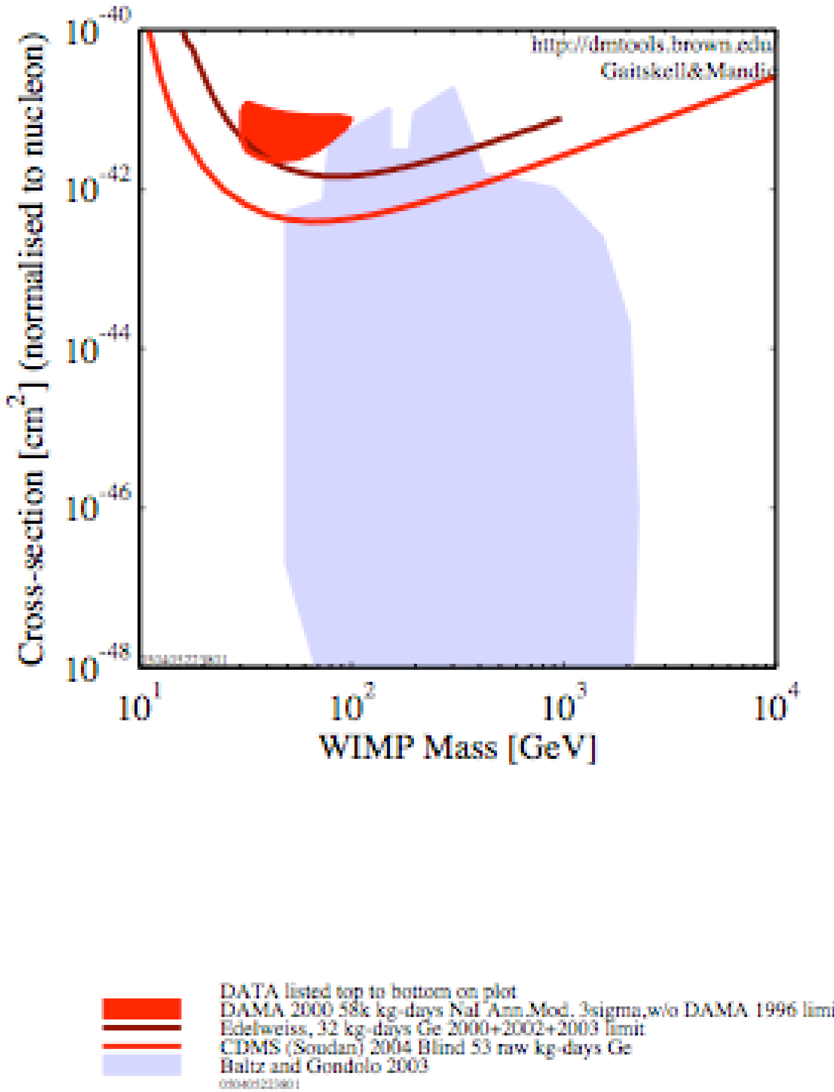


The Milky Way

SUSY Dark Matter: elastic scattering cross section

- The ‘standard’ progress plot in our business
  - Sample SUSY parameter space
  - Apply accelerator and other particle physics constraints
  - Bound on relic density, eg, WMAP

→ Extract WIMP-nucleon cross-section (~event rate) versus WIMP mass



Experimental bounds & unconstrained models

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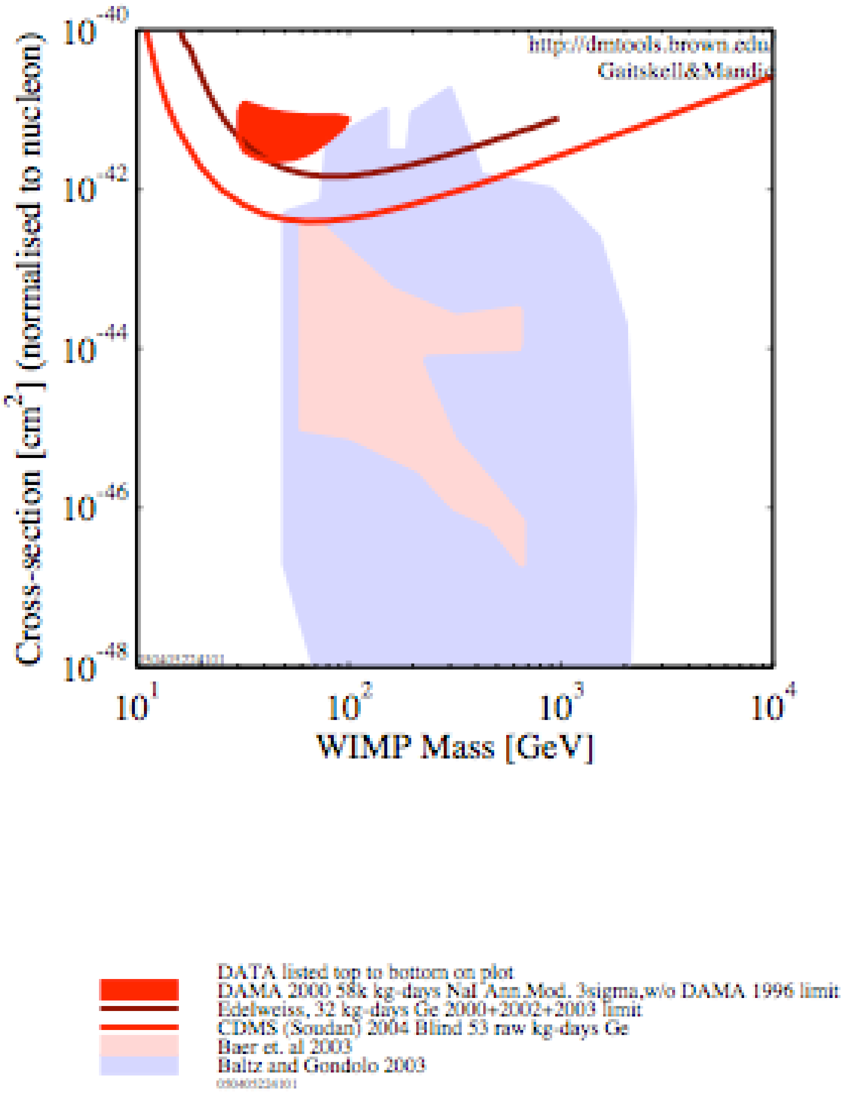

Constrained by theory

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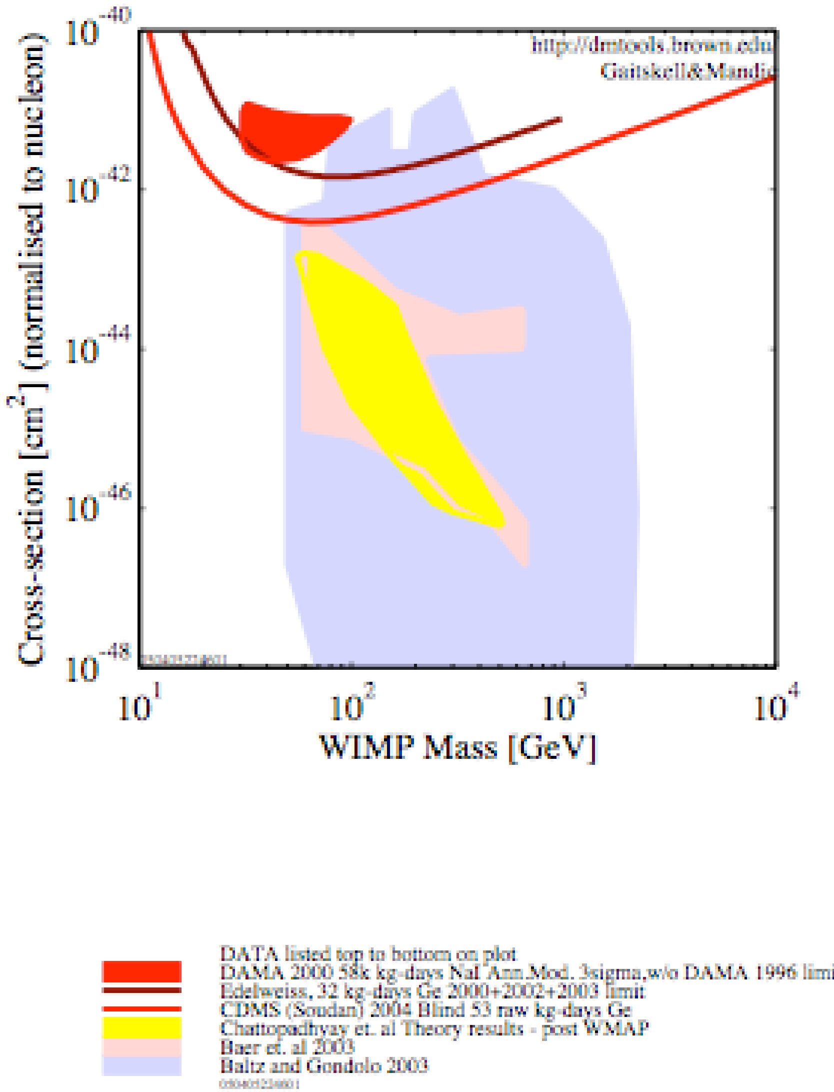

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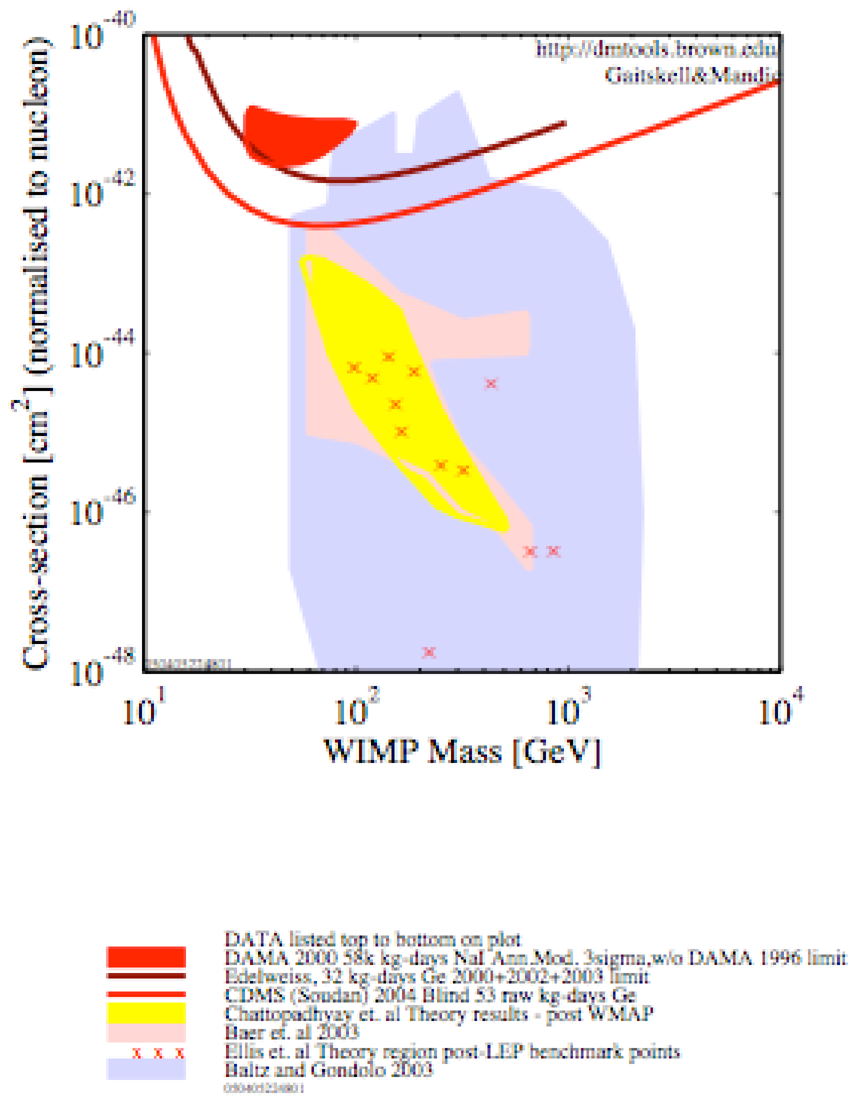

Theoretical benchmarks

SUSY Dark Matter: elastic scattering cross section

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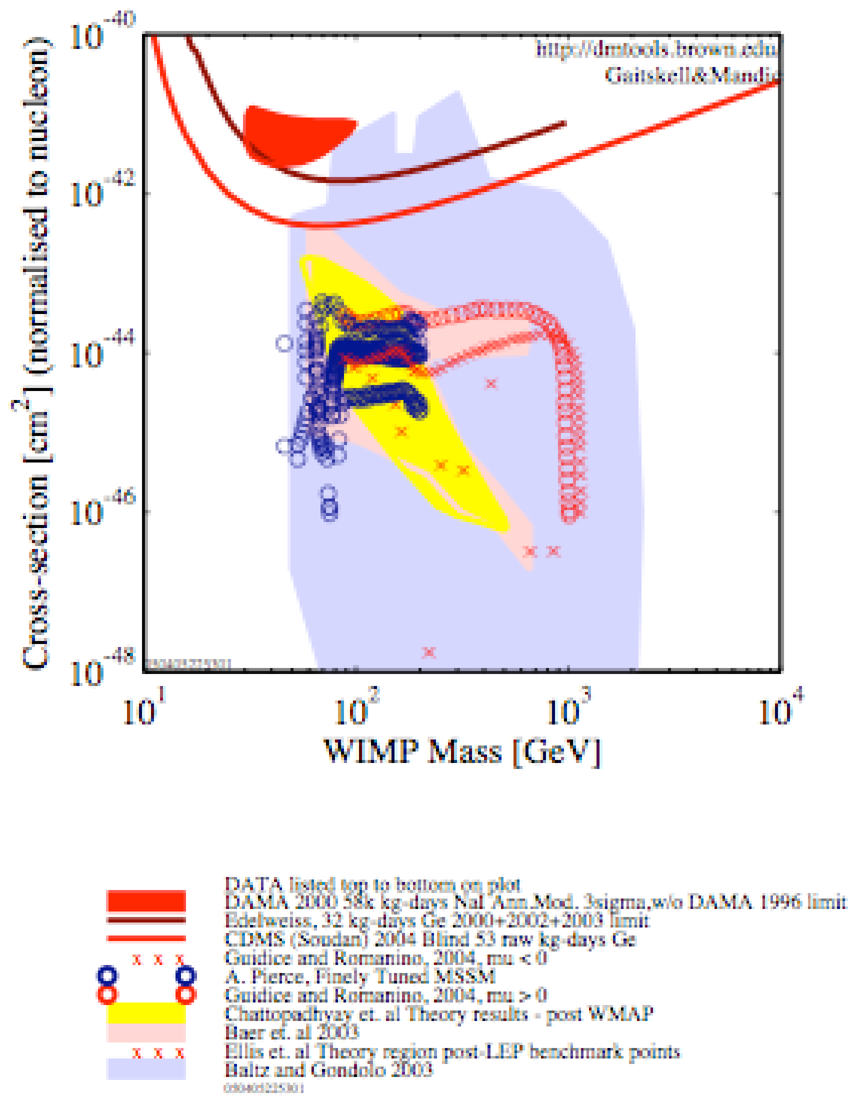

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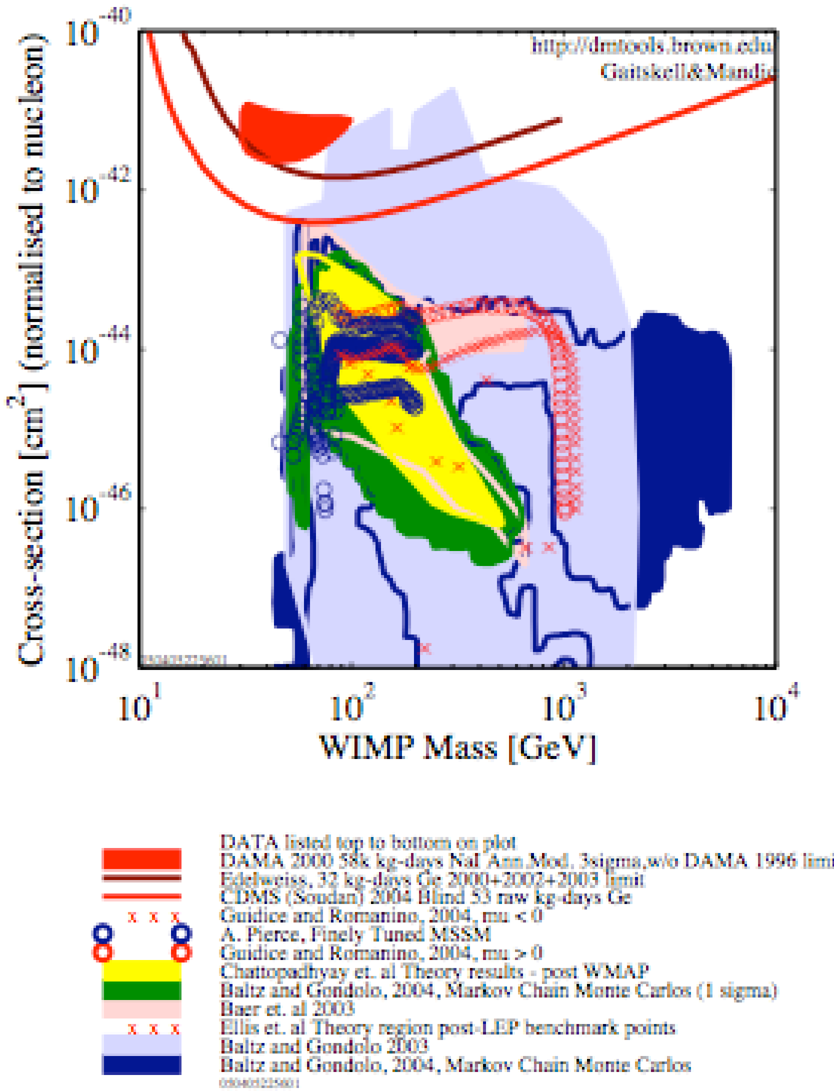

Muon g-2 from SUSY?

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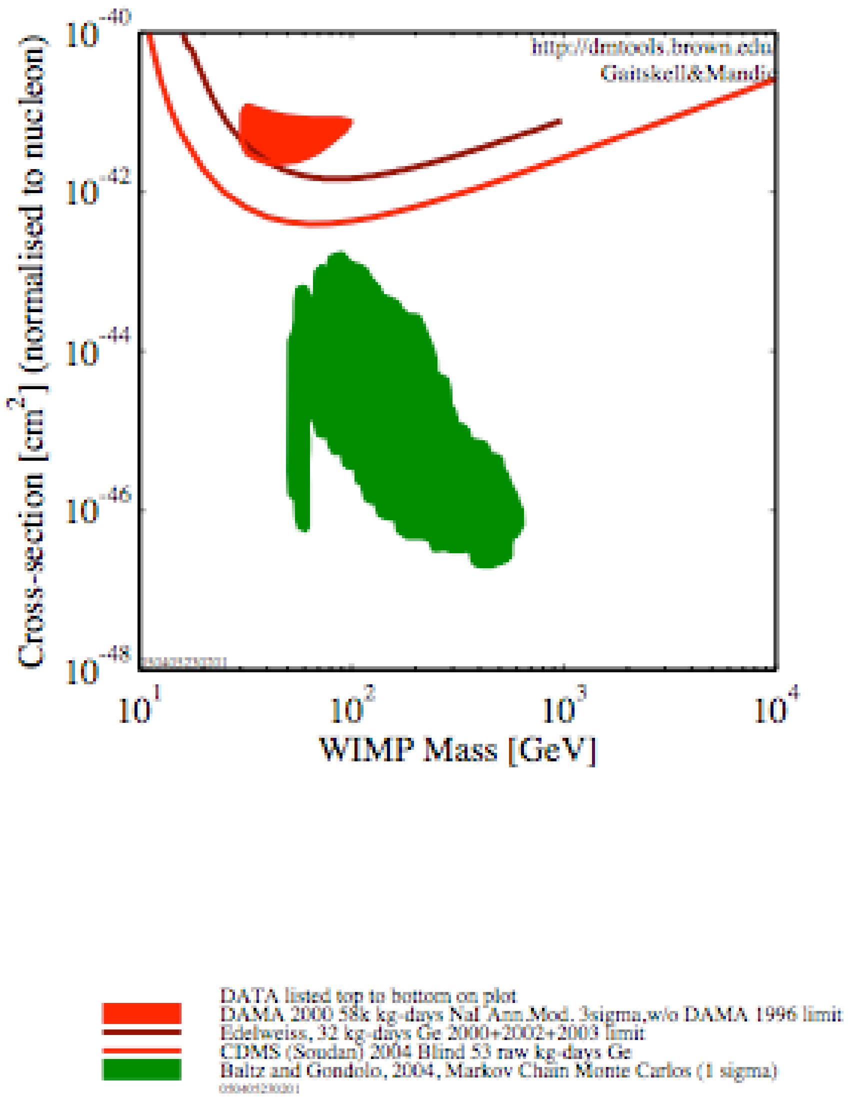
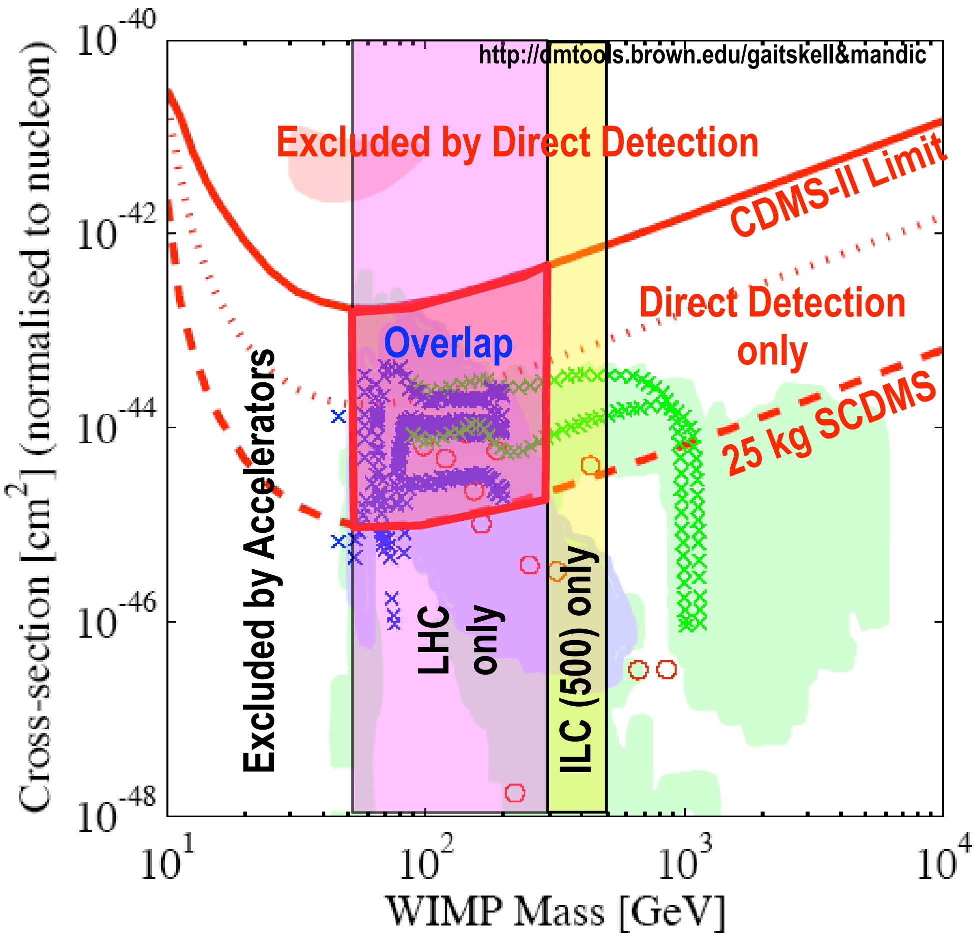


Muon g-2 from SUSY?

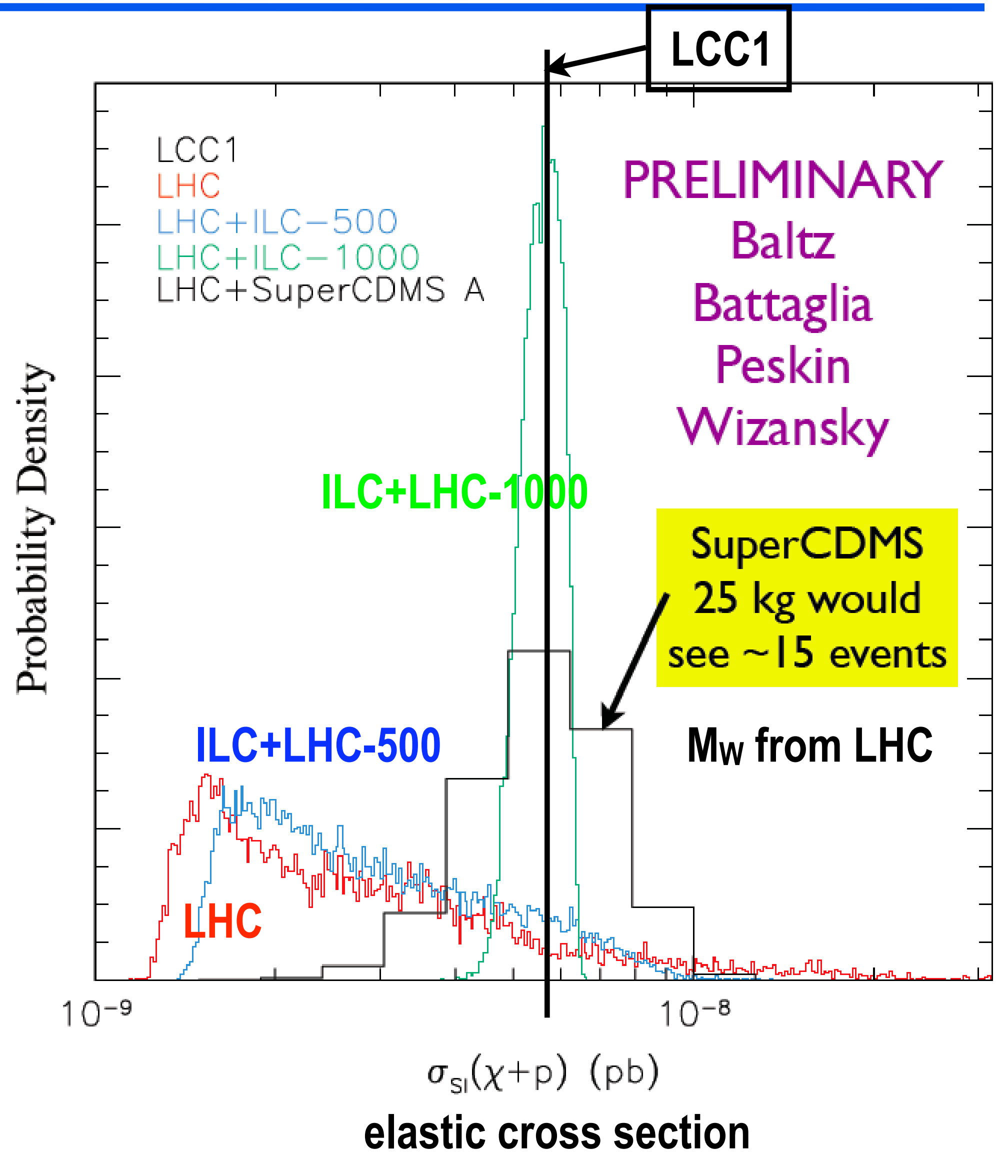
Direct Detection and Accelerators



- **Broad mass range of Direct Detection**
  - LHC has 2 Tev limit for gluino, squark, slepton: neutralinos only up to 300 GeV in most SUSY models
  - Direct Detection may indicate a mass too large for LHC and provide clues for ILC
- **Accelerators reach down to lower elastic cross section**
  - Potential guidance for direct detection searches
- **Rich physics in overlap region of LHC and 10–100 kg DM expt**
  - Exciting opportunity to establish concordant model

WIMPs and SUSY

- **LHC/ILC constraints compared with direct DM searches by Linear Collider Cosmology working group**
  - Specify a benchmark model, eg, here LCC1 is mSugra ‘bulk region,’ consistent with WMAP relic density
  - Explore range of all models compatible with accelerator data
  - Constrain secondary parameters, eg, neutralino mixing angles and elastic cross section



How do we make measurements?

What nature has to offer

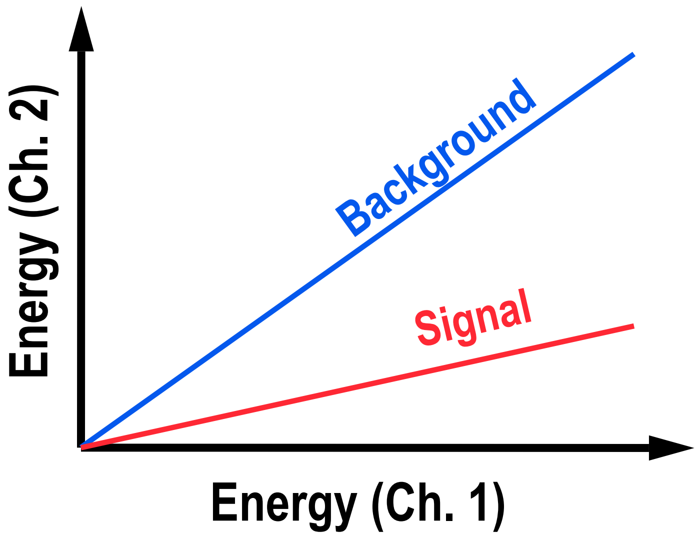
What you hope for!

Getting rid of the 'haystack': Recoil Discrimination

WIMPs 'look' different – recoil discrimination

Photons and electrons scatter from electrons

WIMPs (and neutrons) scatter from nuclei



- Measure division of deposited energy into multiple channels
  - ionization
  - heat
  - athermal phonons ⇒ timing
  - scintillation ⇒ timing
- Exploit differential response
- Also, background immunity from
  - directional
  - threshold

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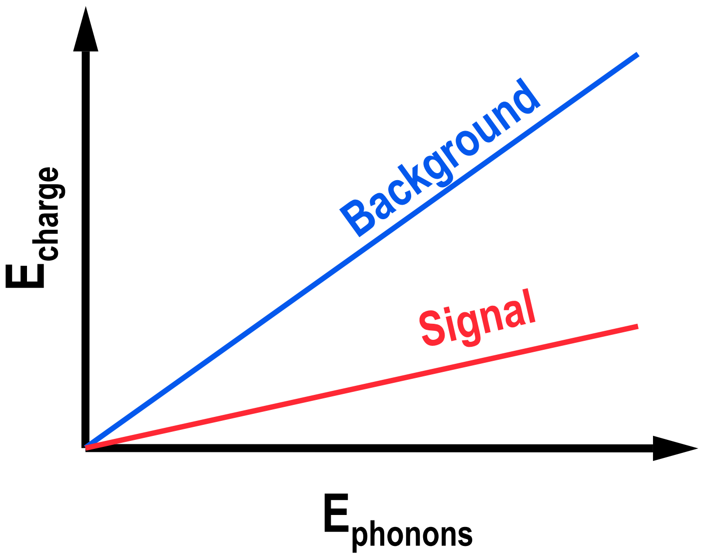

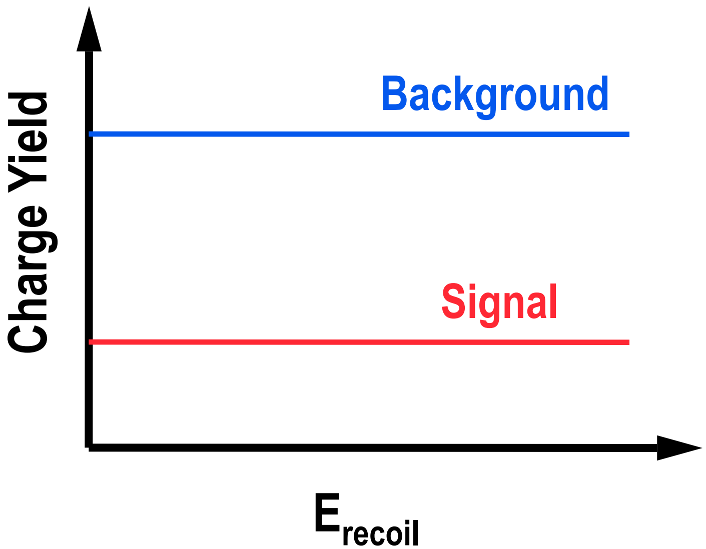

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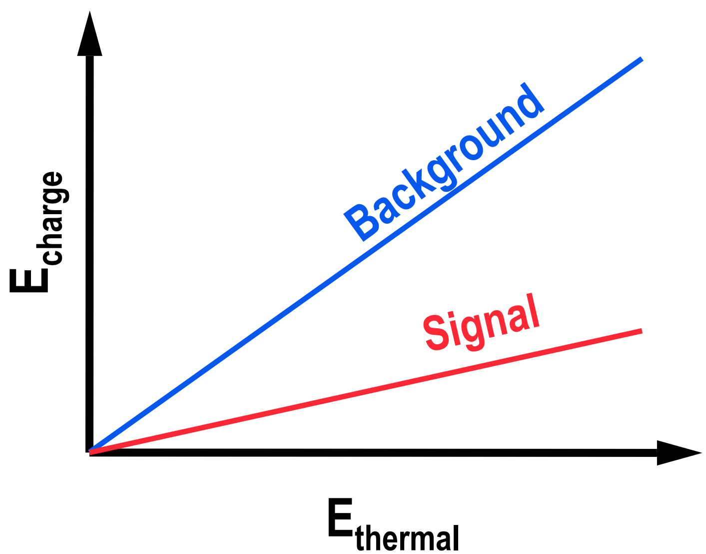

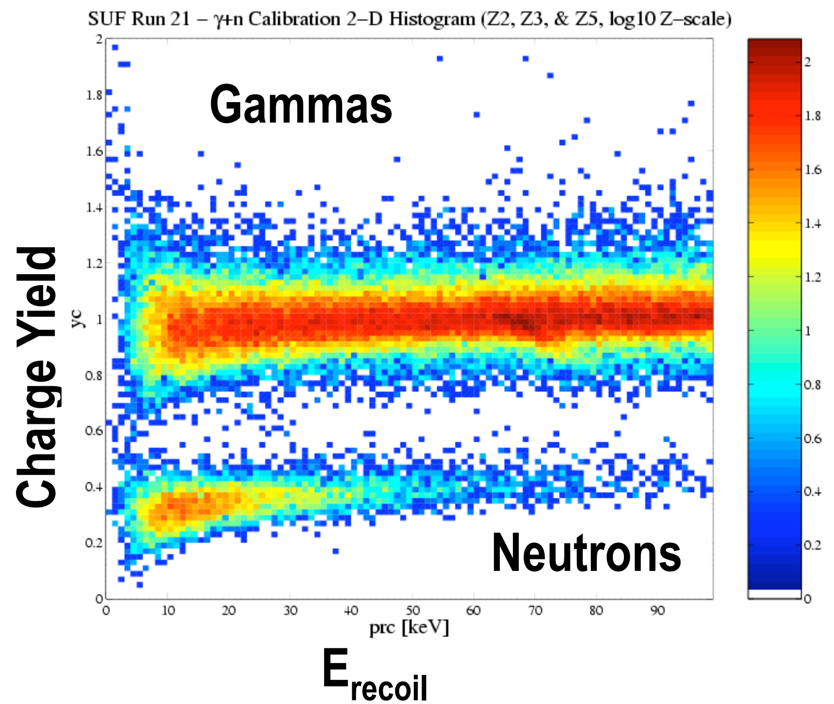

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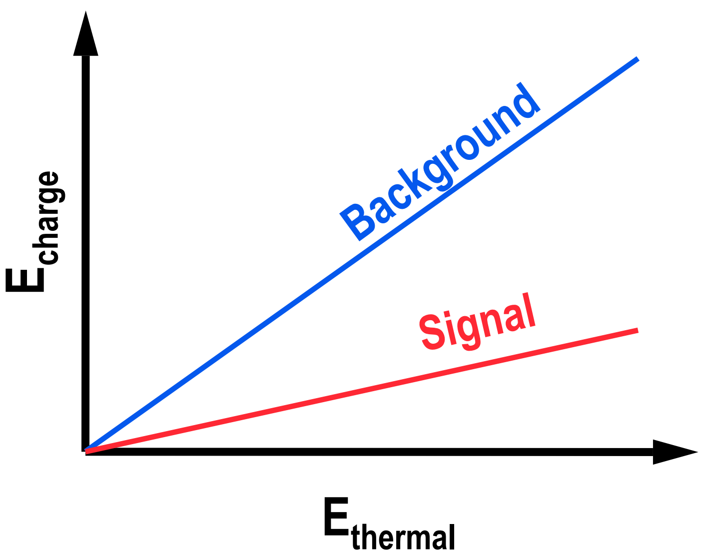
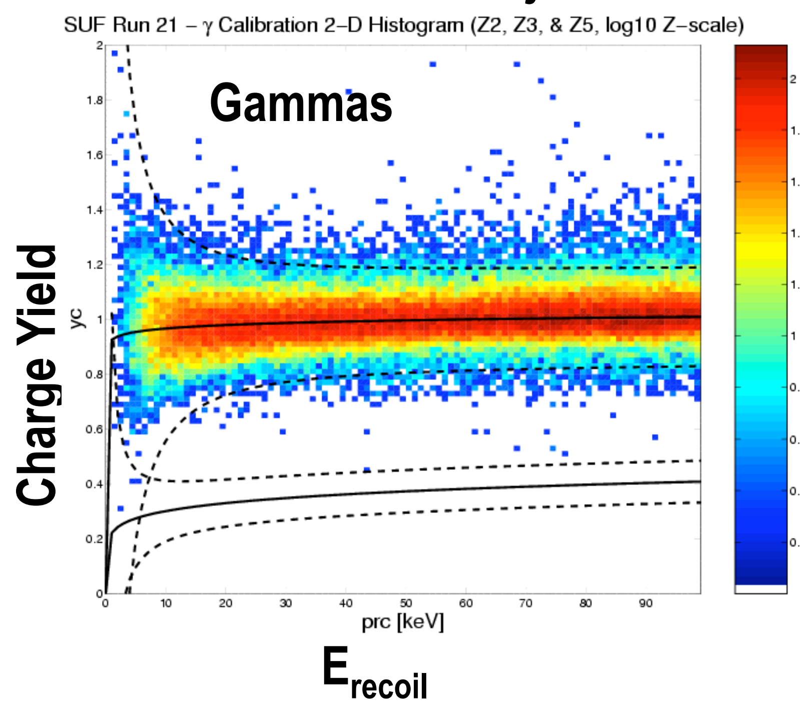


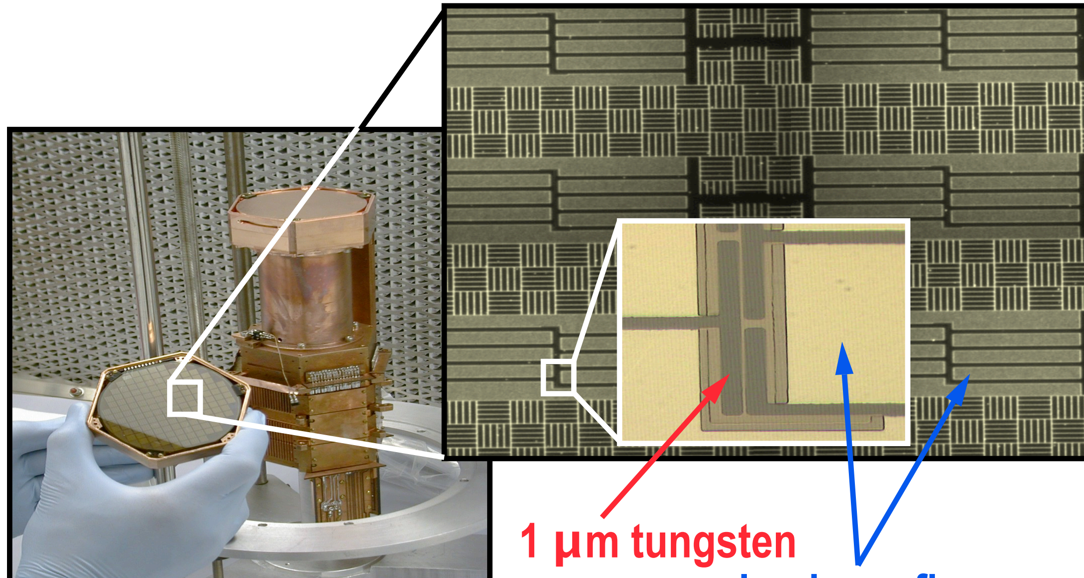
>50000:1 rejection



CDMS: Cryogenic “ZIP” detectors

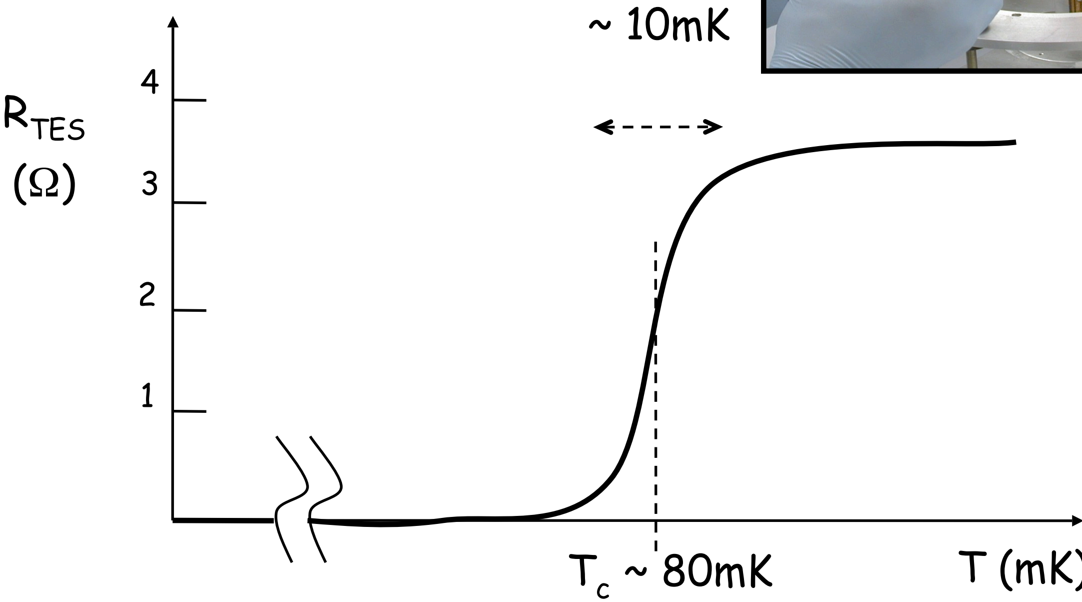
Superconducting films that detect minute amounts of heat

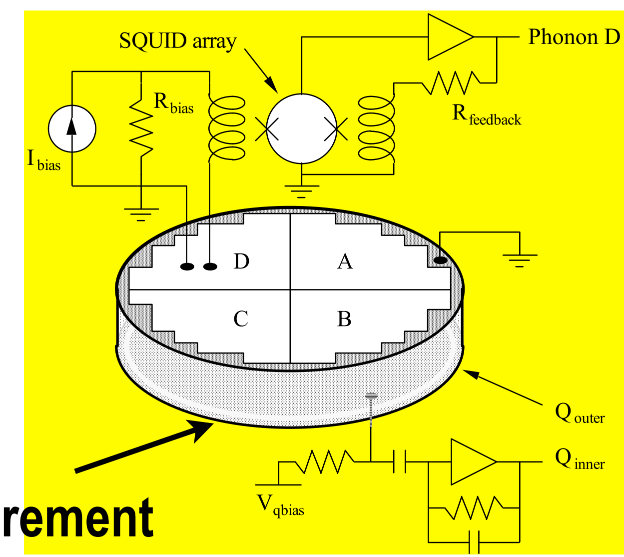
Transition Edge Sensor sensitive to fast athermal phonons



1 µm tungsten

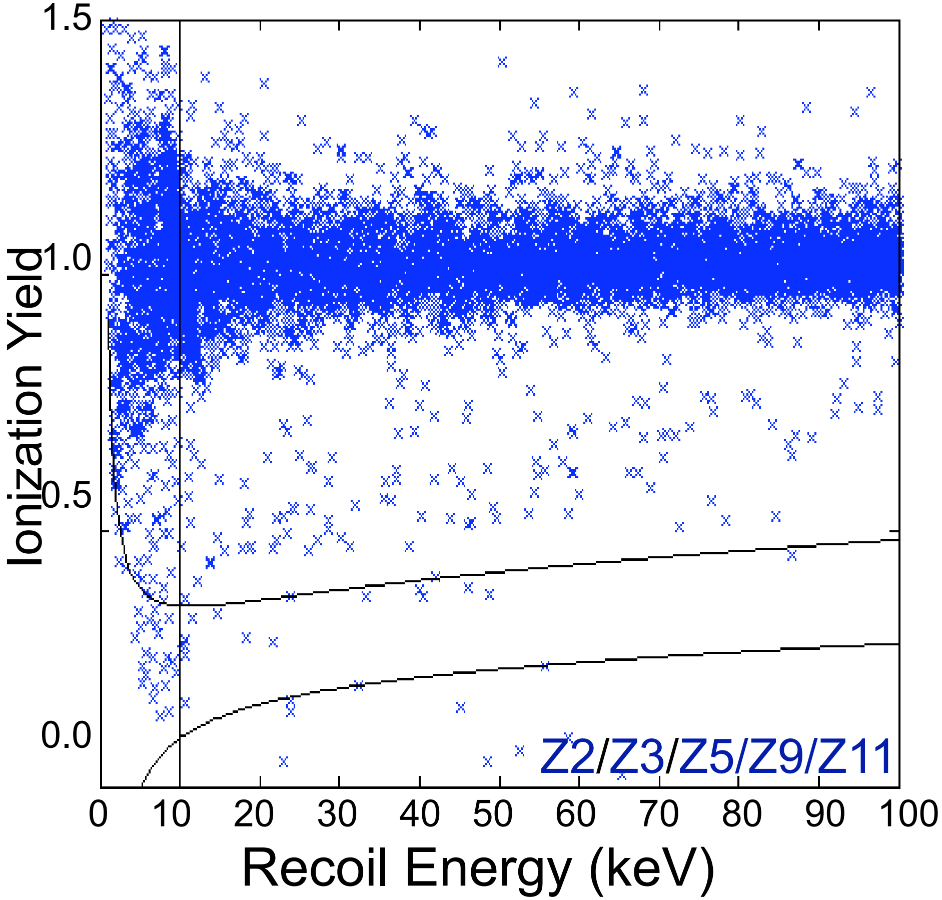
aluminum fins

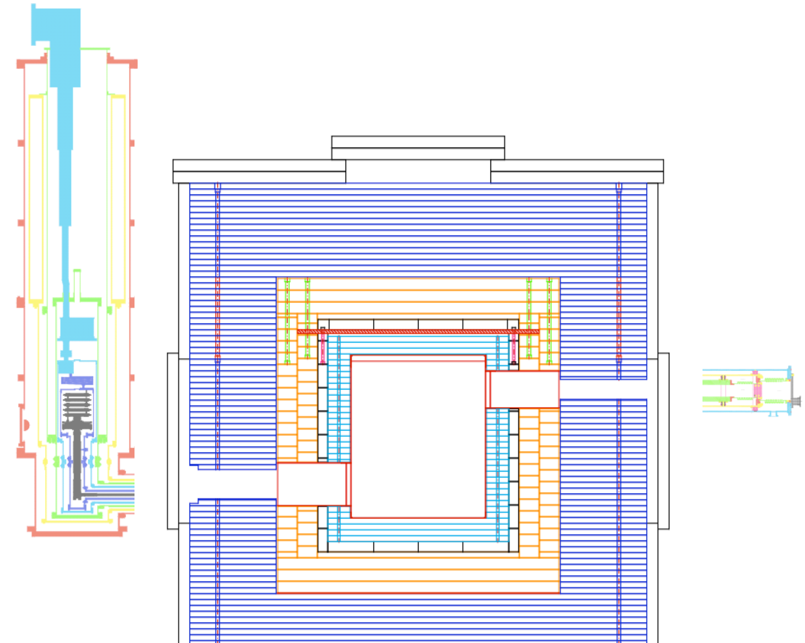




Ionization measurement

Second Soudan Run WIMP-search data

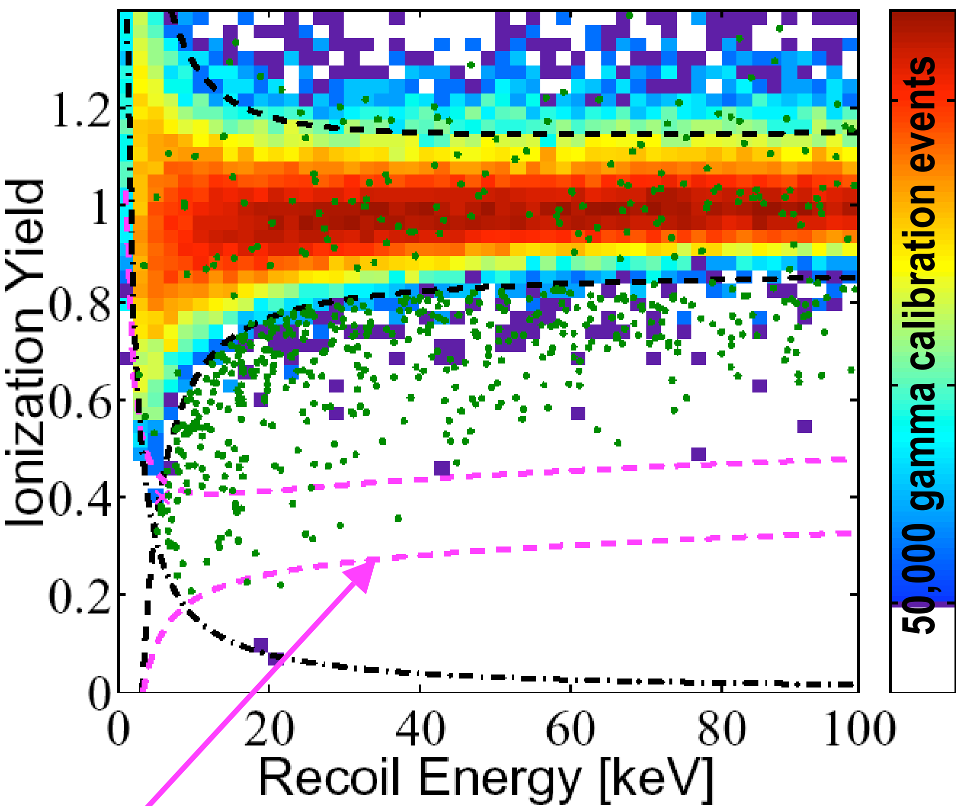




34 kg-d after cuts

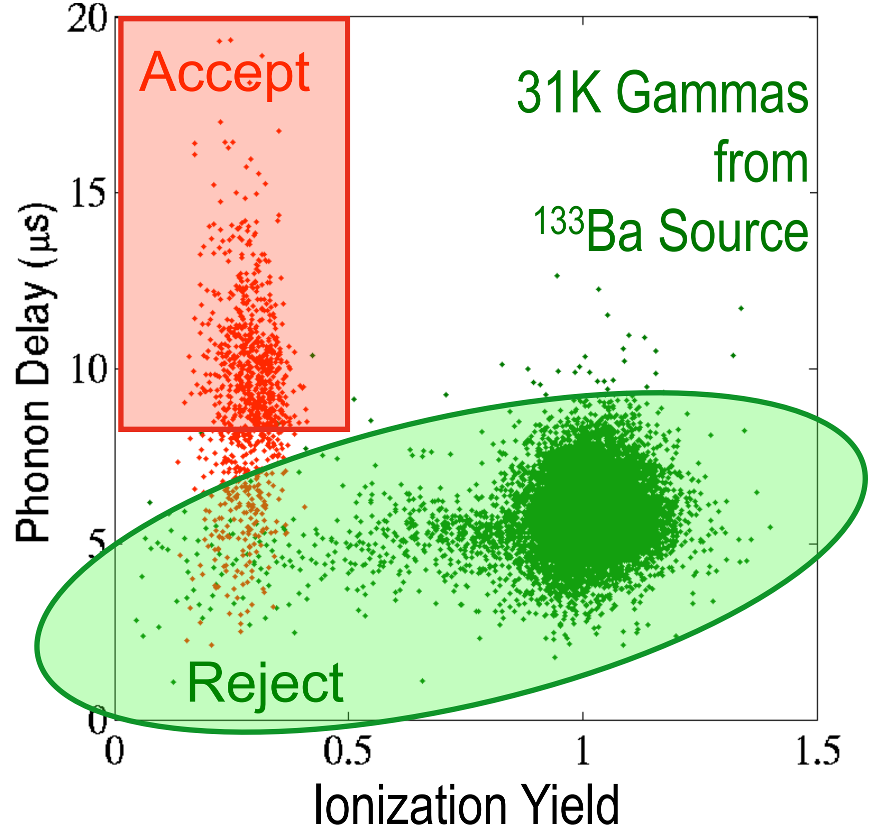
Betas: a low-yield background source

- Low-energy electrons (tagged •) that interact in detector surface "dead layer" result in reduced ionization yield



Nuclear-recoil WIMP-signal region

Neutrons from ^{252}Cf source



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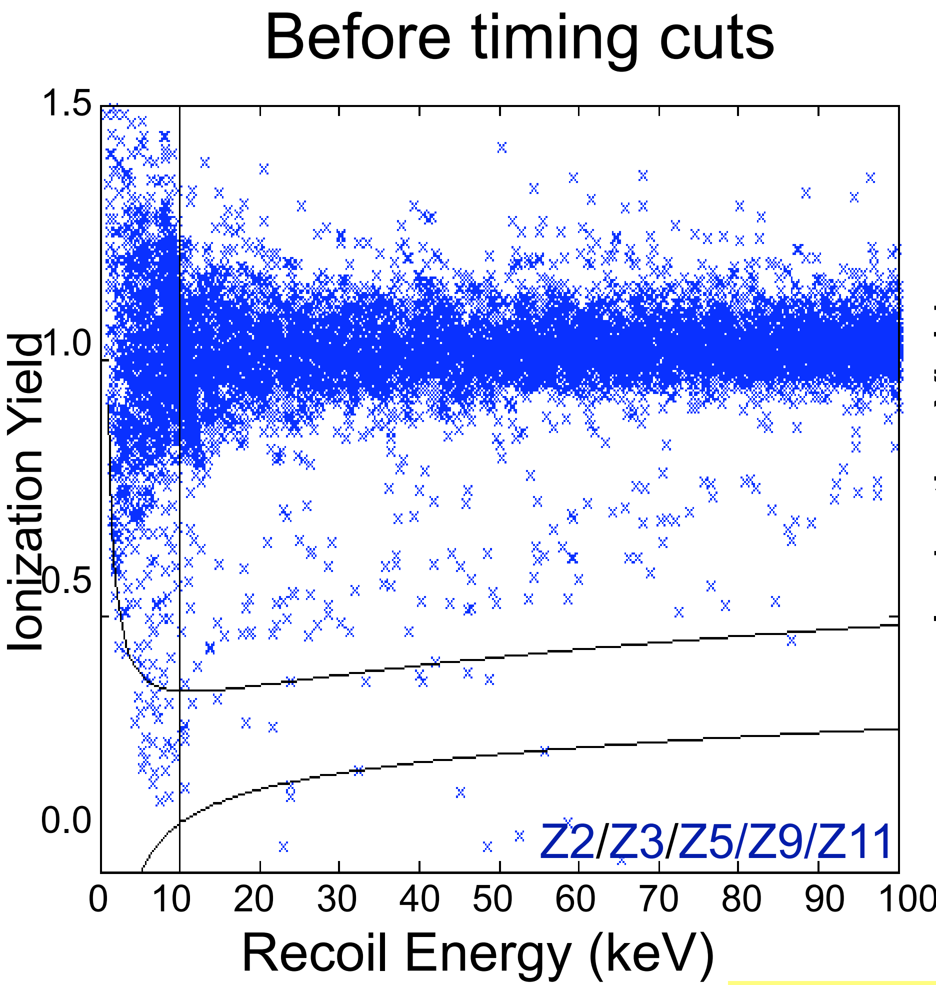
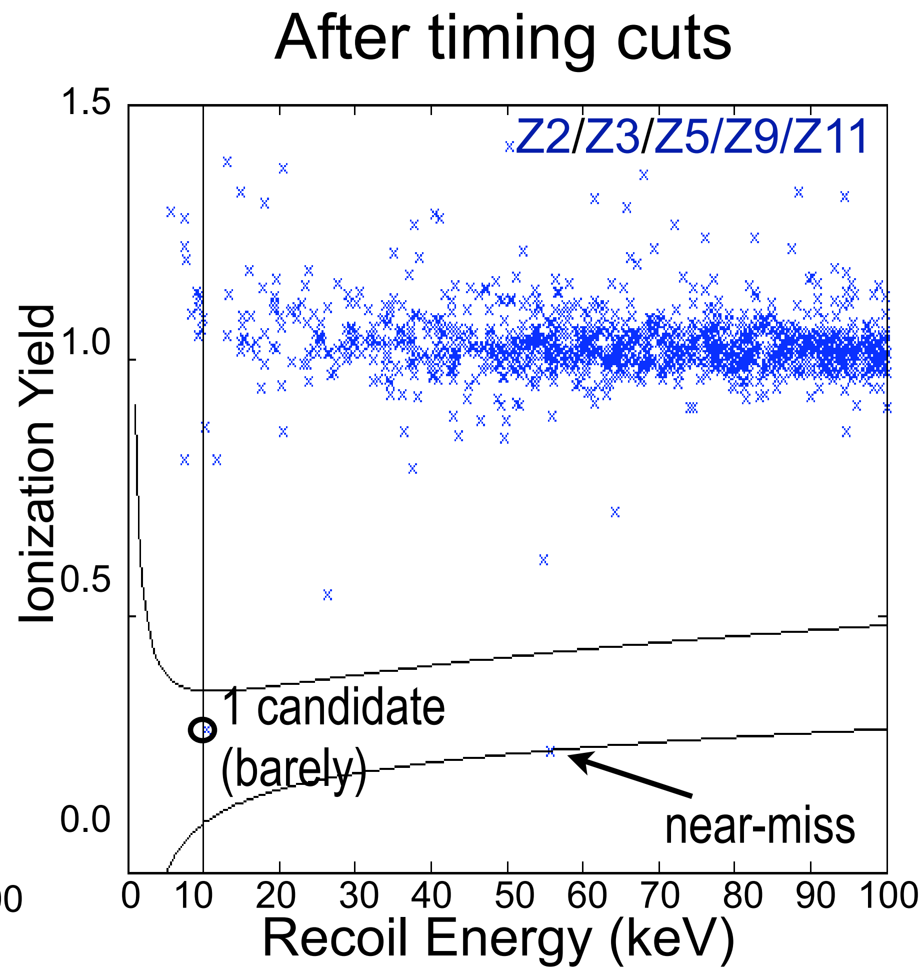


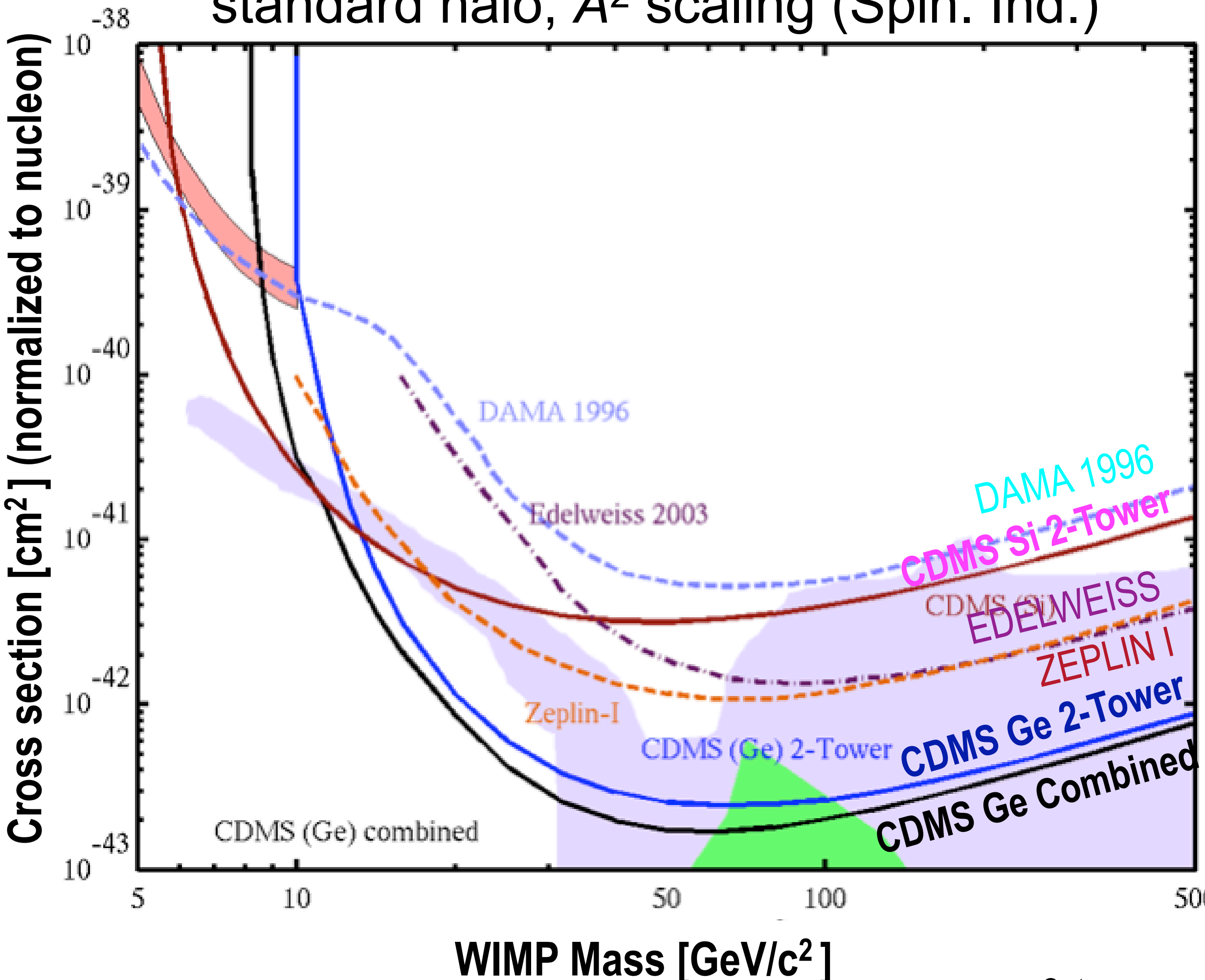


34 kg-d after cuts

ESTIMATE BKG: 0.4 ± 0.2 (sys.) ± 0.2 (stat.) electron recoils, 0.05 recoils from neutrons expected.
Optimized for ~0.5 background events

1st Year CDMS Soudan Combined Limits

90% CL upper limits assuming standard halo, A^2 scaling (Spin. Ind.)



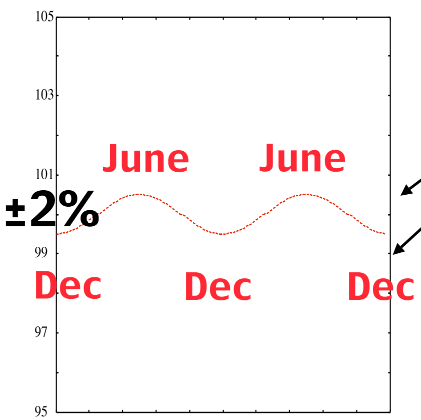
- **Upper limits on the WIMP- nucleon cross section are 1.7×10^{-43} cm^2 for a WIMP with mass of 60 GeV/c^2**
  - **Factor 10 lower than any other experiment**
- **Excludes regions of SUSY parameter space under some frameworks**
  - **Bottino et al. 2004 in magenta (relax GUT Unif.)**
  - **Ellis et al. 2005 (CMSSM) in green**

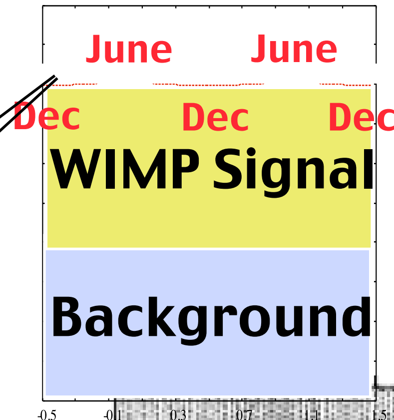
2-tower and combined: astro-ph/0509259

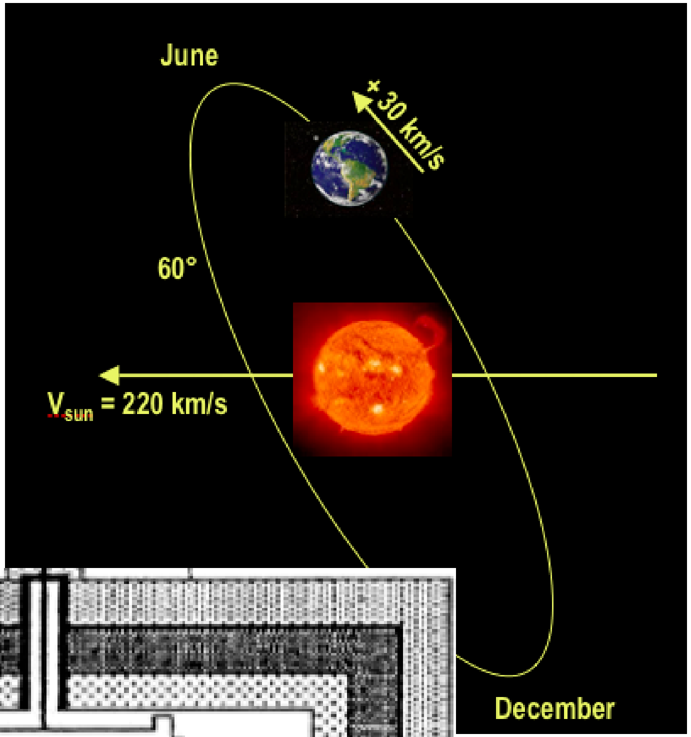
*1-tower: PRL **93**, 211301 (2004); PRD **72**, 052009 (2005)*

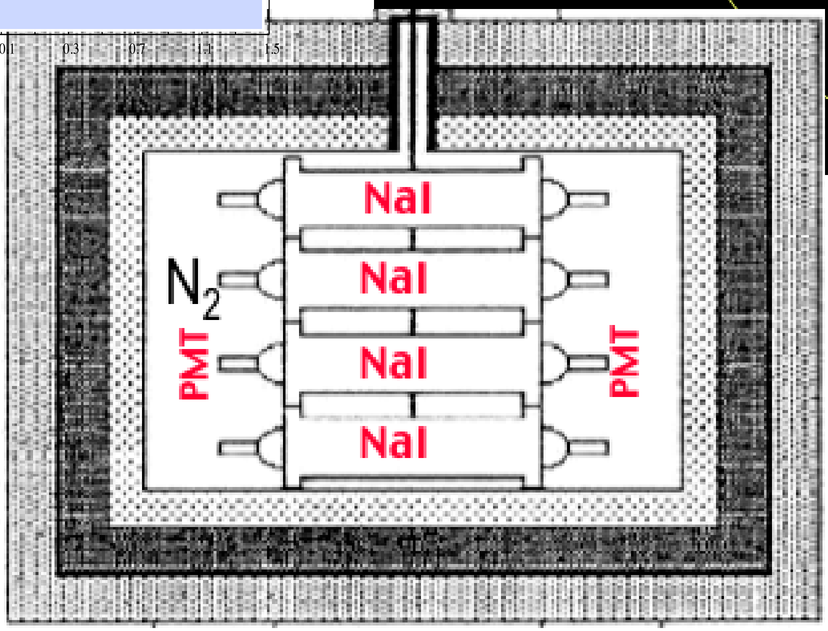
DAMA: NaI & Annual Modulation

100-kg detector mass, but no rejection of gamma background









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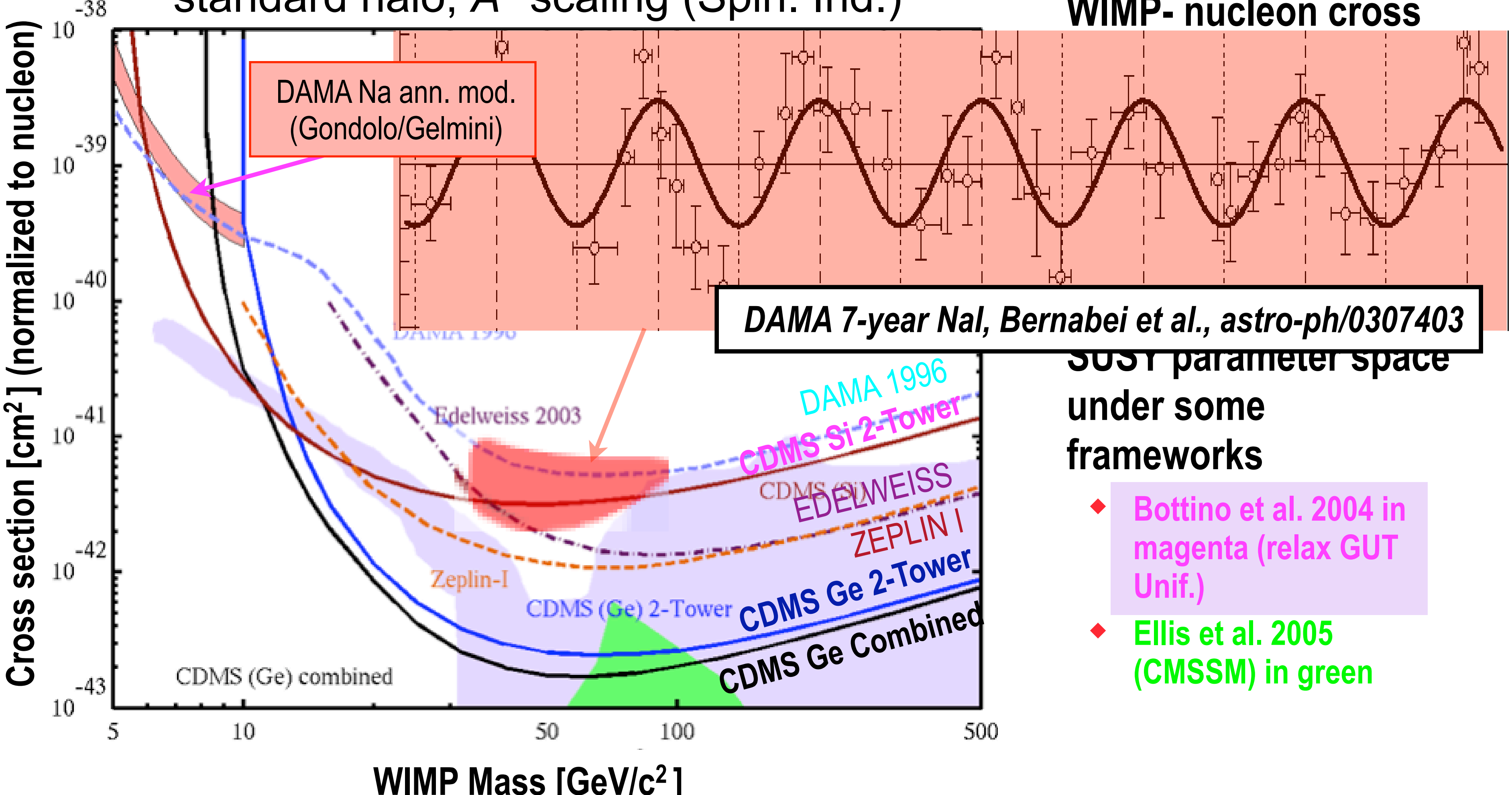

- **Upper limits on the WIMP- nucleon cross**

  SUSY parameter space under some frameworks
  - **Bottino et al. 2004 in magenta (relax GUT Unif.)**
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2-tower and combined: astro-ph/0509259

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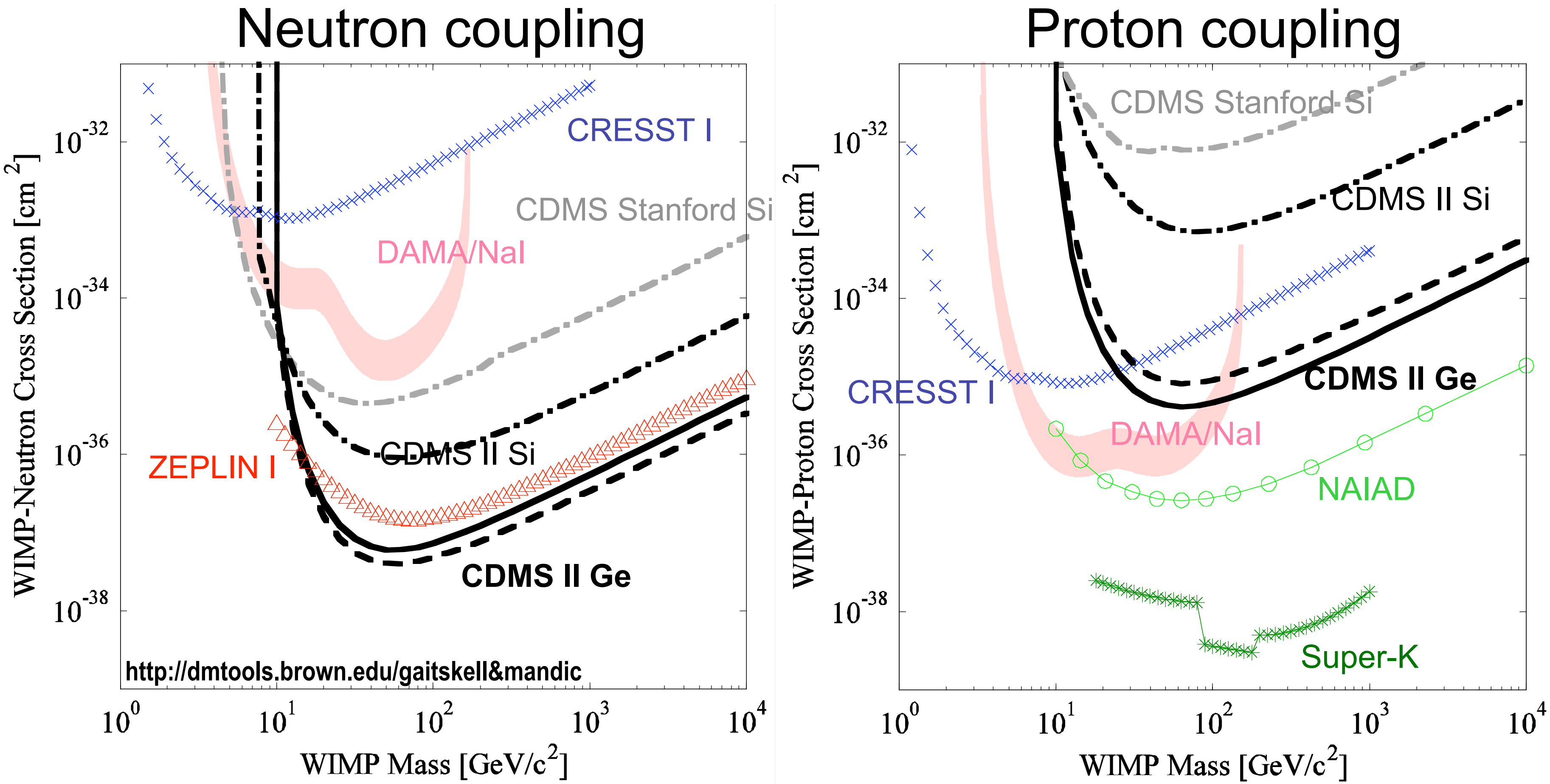
Spin-Dependent WIMP limits

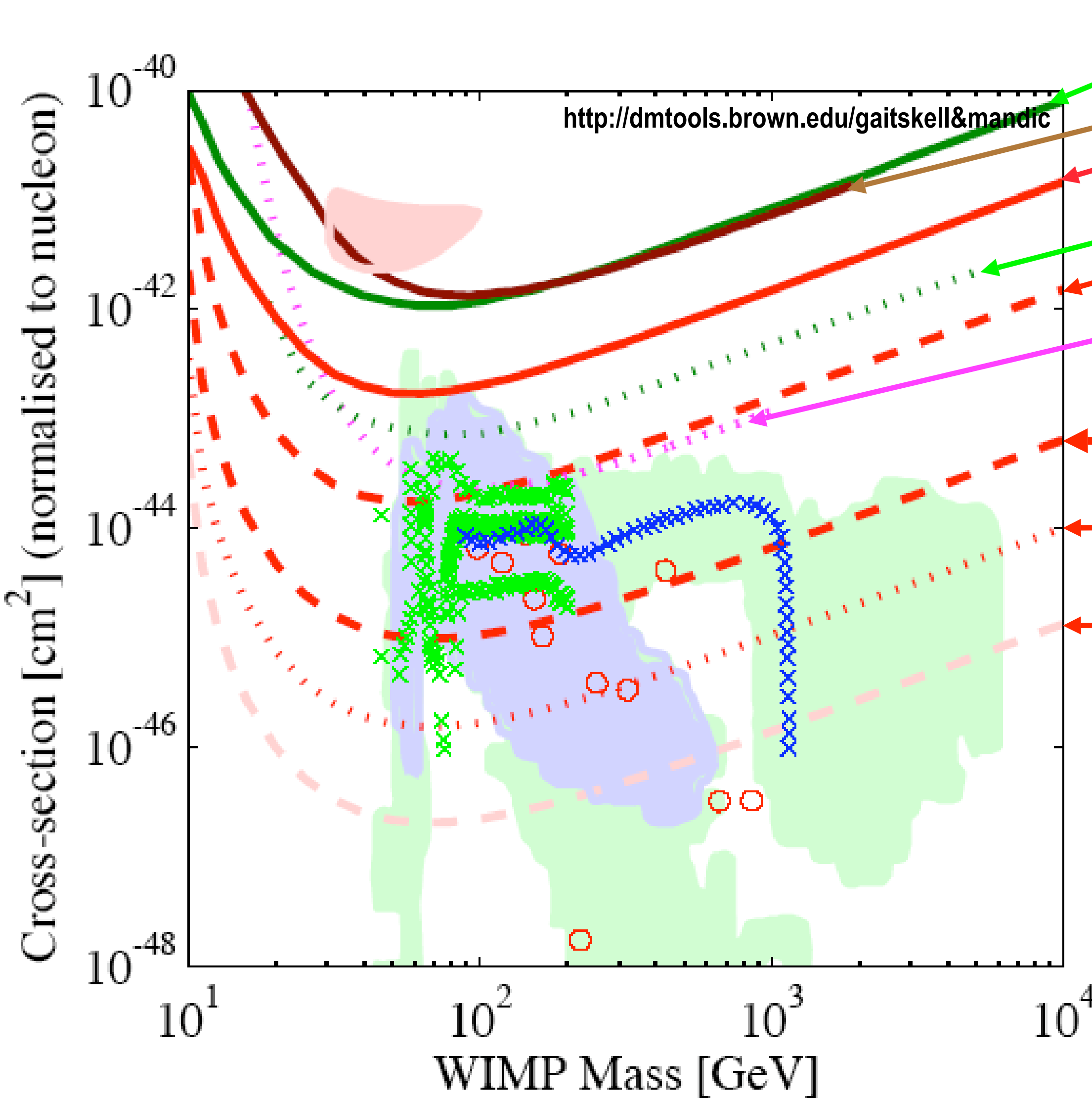


different nuclear form factors

astro-ph/0509269

Following the method of C. Savage, P. Gondolo, and K. Freese, PRD70, 123513 (2004) (astro-ph/0408346).

Soudan and beyond: phased approach to 1-ton



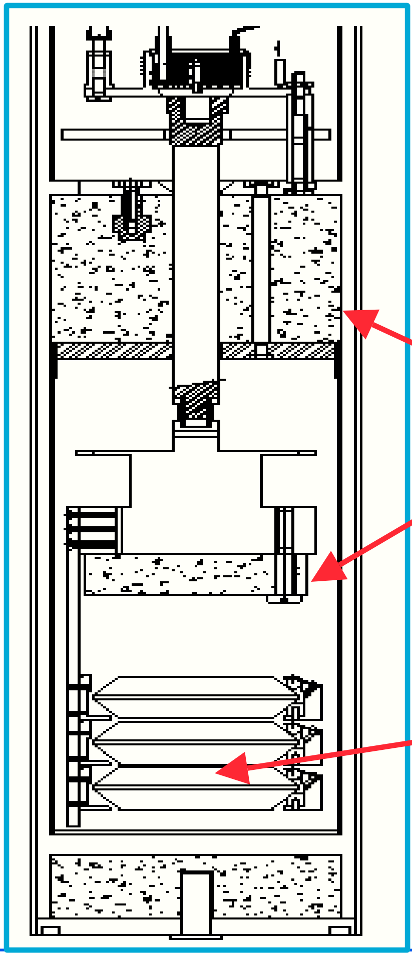
- **Maximize discovery potential**
  - **Background-free**
  - **Lots of information on each event**

25-kg technically ready and endorsed by SNOLab

Survey of other techniques

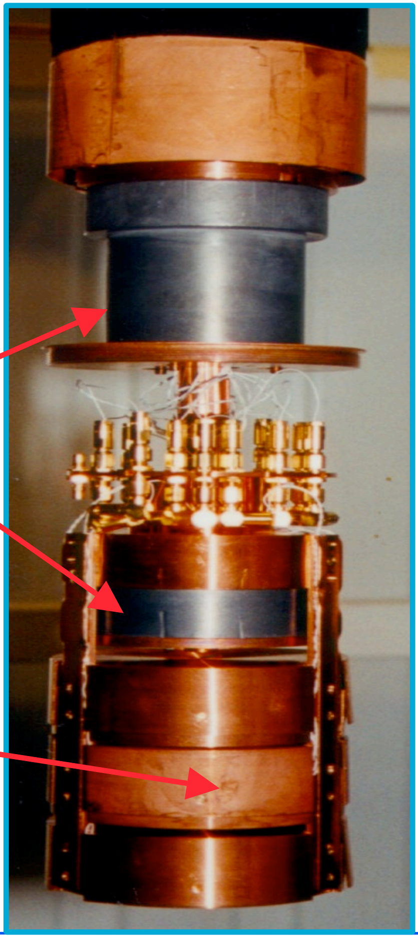
Edelweiss-I in Frejus Tunnel: "1 kg" stage

- First data taking in Fall 2000 at 4800 mwe depth
- Detector improvements: 2nd data set early 2002
- 3rd data taking: October 2002 - March 2003



Archeological
lead

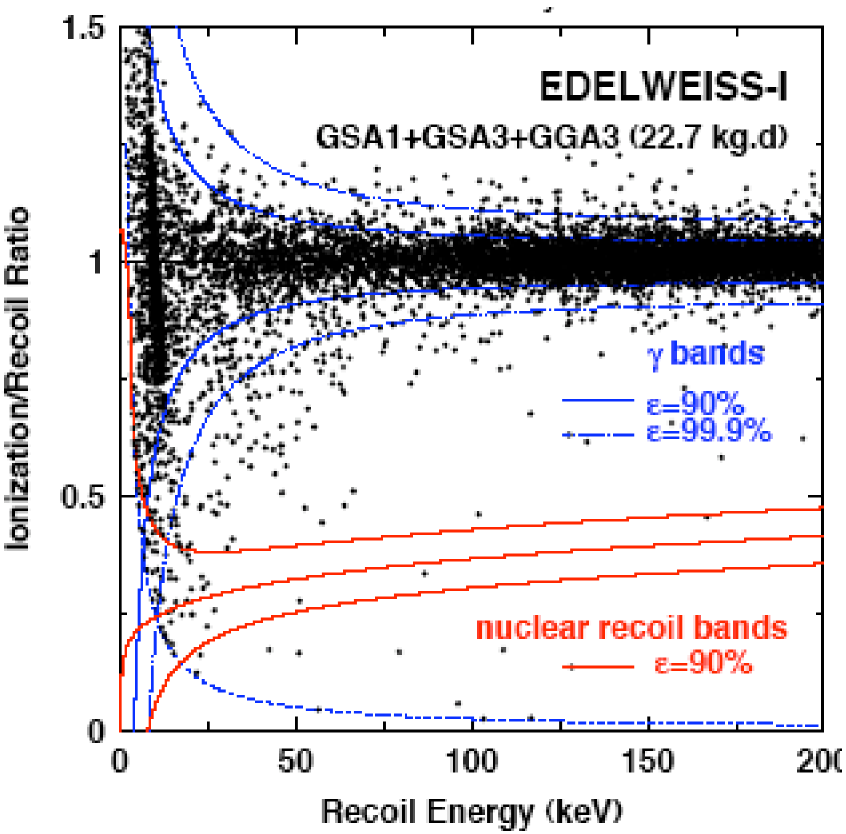
3 * 320 g Ge detectors:
heat and ionization
simultaneous readout
(NTD thermistor)
Installed May 2002



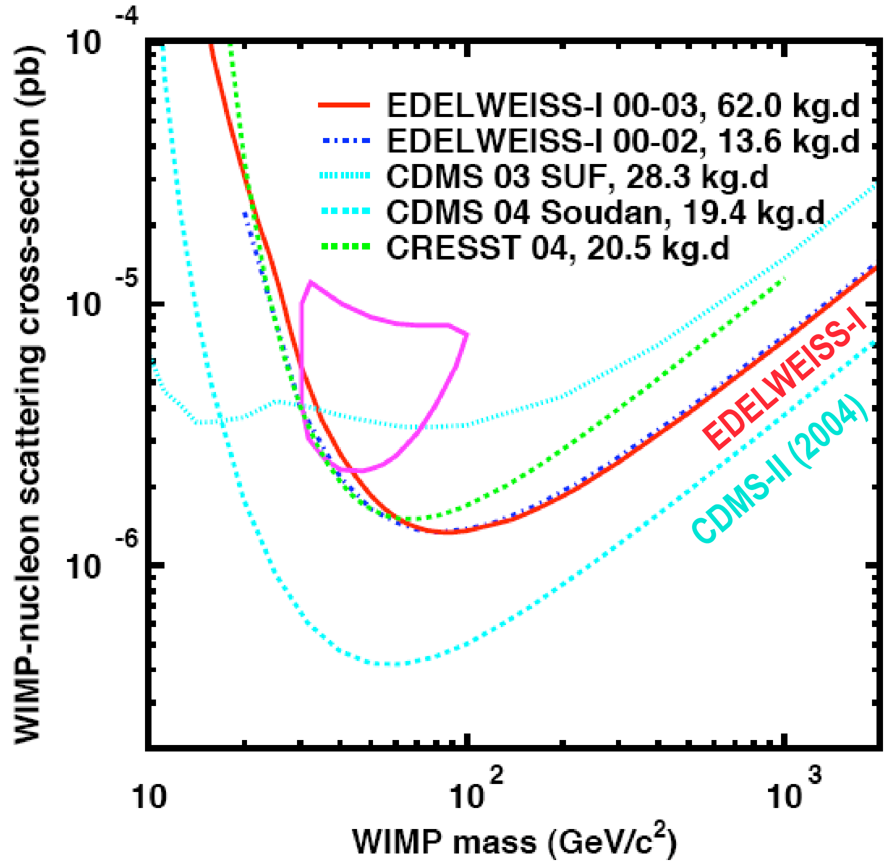
EDELWEISS-I results

- 2000-2003: Exposure of ~60 kg-d
  - Three nuclear recoil candidates (30-100keV) consistent with neutron bkg

WIMP search data (partial)



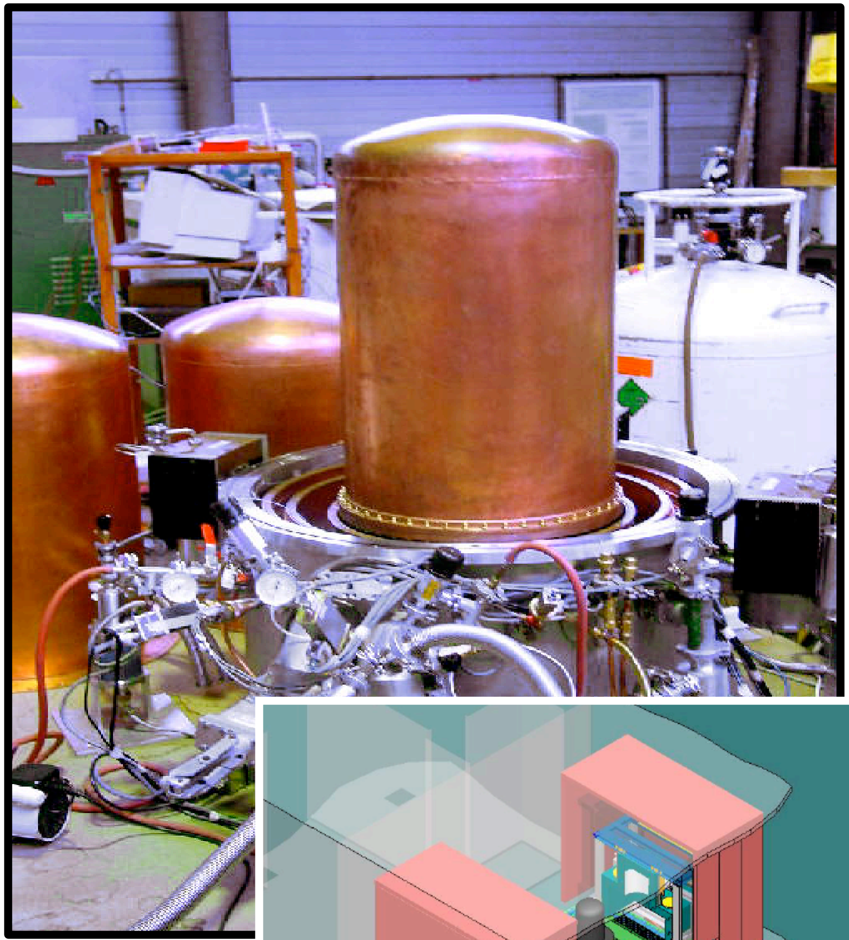
WIMP cross section limit

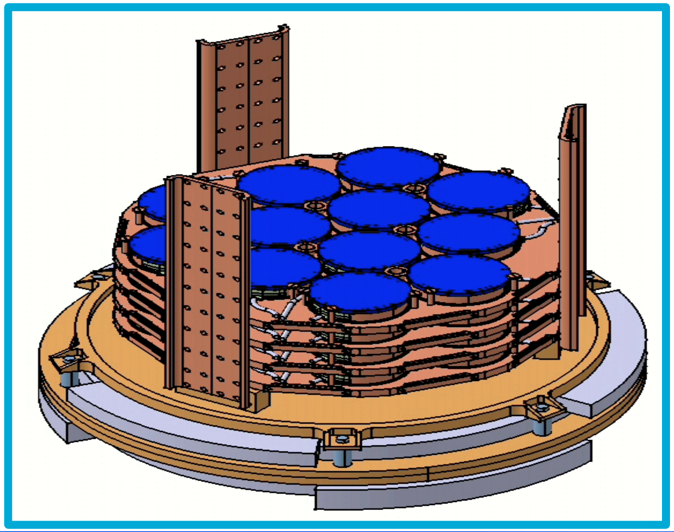


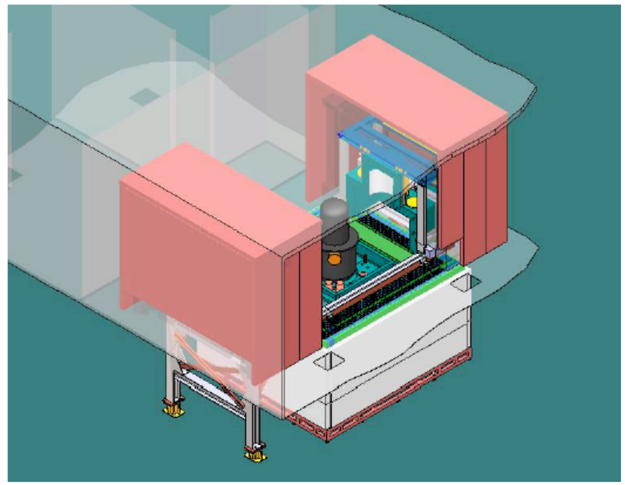
astro-ph/0503265

Edelweiss-II

- 100-detector cryostat being installed at Frejus
- Phase 1 detectors:
  - 21 x 320-g NTD detectors ready
  - 7 x 400-g NbSI detectors - expected end of 2005
    - metal-insulator transition - additional fast component for surface event discrimination

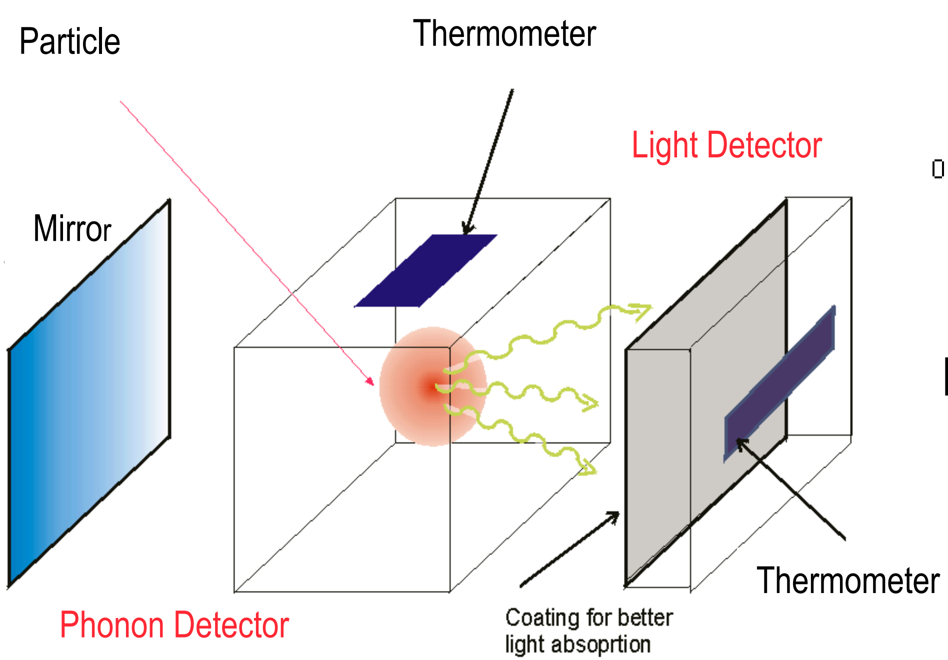


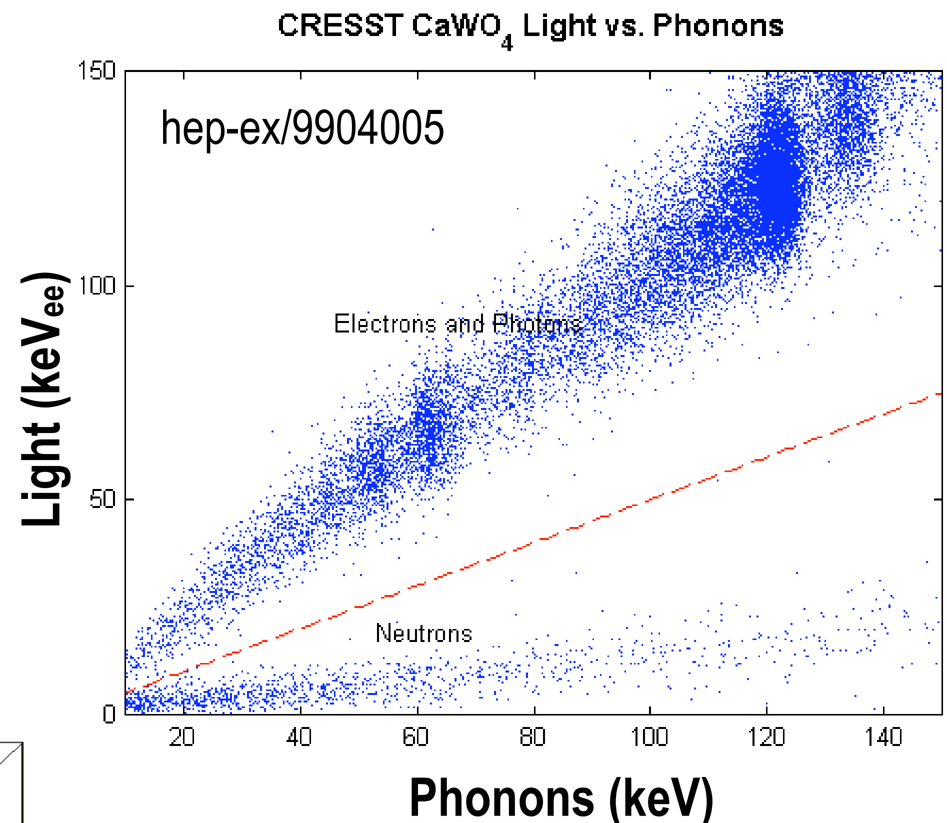




CRESST II: Phonons and Scintillation

- Nuclear recoils have much smaller light yield than electron recoils
- Photon and electron interactions can be distinguished from nuclear recoils (WIMPs, neutrons)

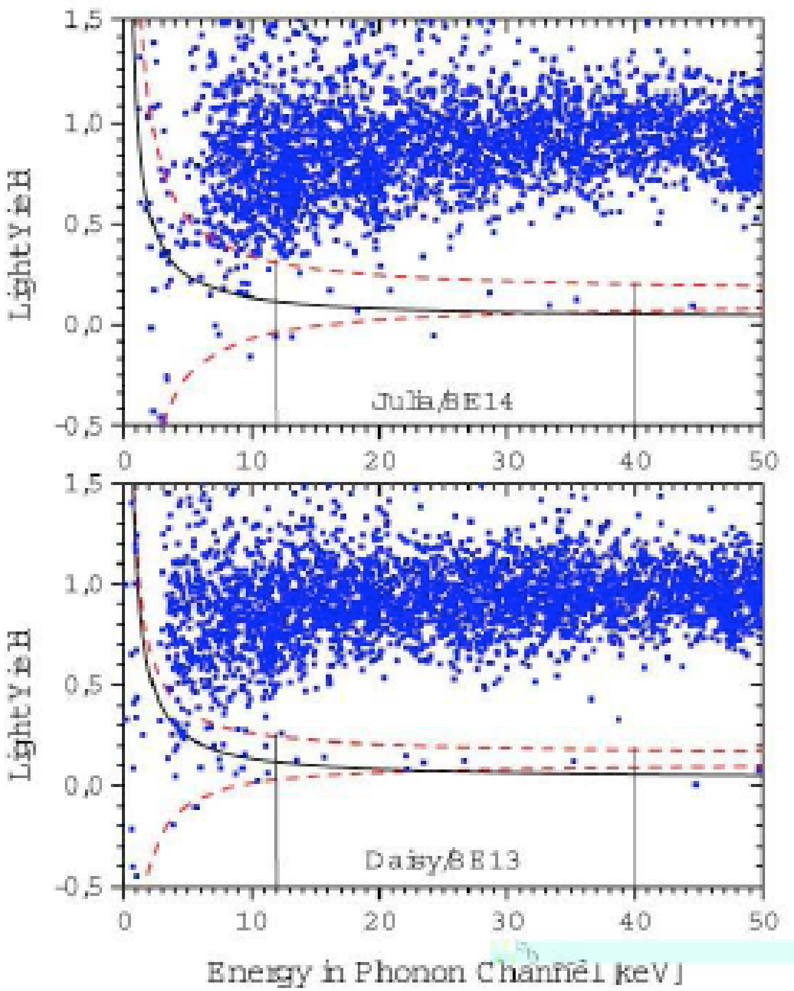




Results from a 6g $CaWO_4$ prototype

- Very small scintillation signal for tungsten recoils
- Scaled up to 300g detectors

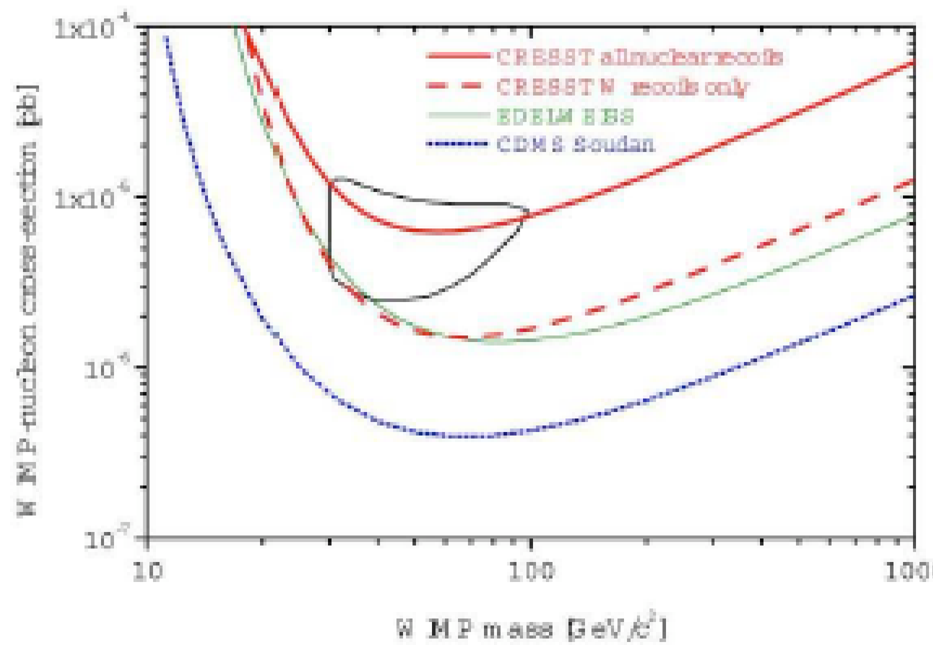
CRESST II: Phonons and Scintillation



Astro-ph/0408006

Results from 20.5 kg-d expoure of two 300-g $CaWO_4$ prototypes

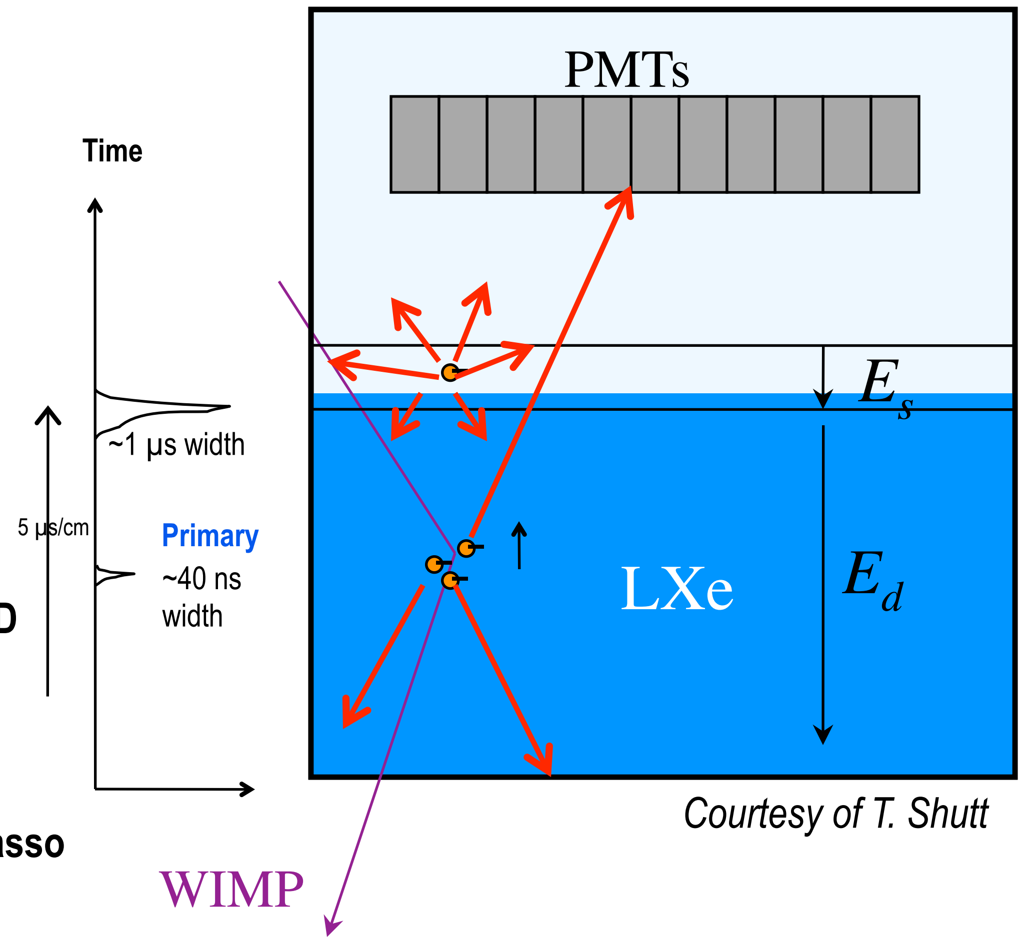
- No neutron shielding
- Observe low-yield events consistent with neutron rates and oxygen cross section & light yield
- Claim no tungsten recoils in light yield region below oxygen yield (not distinct from noise)



Liquid Noble Detectors

- Liquid Xe, Ar, Ne Detectors
- Atomic excimer states provide recoil discrimination
  - Pulse Shape Discrimination
  - Secondary ionization signal
    - eg, dual phase
  - May readily scale to large mass
- Challenges
  - discrimination at low threshold
  - ^{87}Kr, ^{39}Ar backgrounds
- Several programs
  - Zeplin (UK/UCLA) – Xenon
    - RESULTS from single phase PSD
    - Dual phase under construction
  - XENON (Columbia, Brown, Case, Yale, Florida)
    - 10-kg in construction at Gran Sasso
  - DEAP (LANL, Queens) – Argon
  - CLEAN (Yale, LANL) – Neon

Dual-phase LXe Time Projection Chamber (TPC)

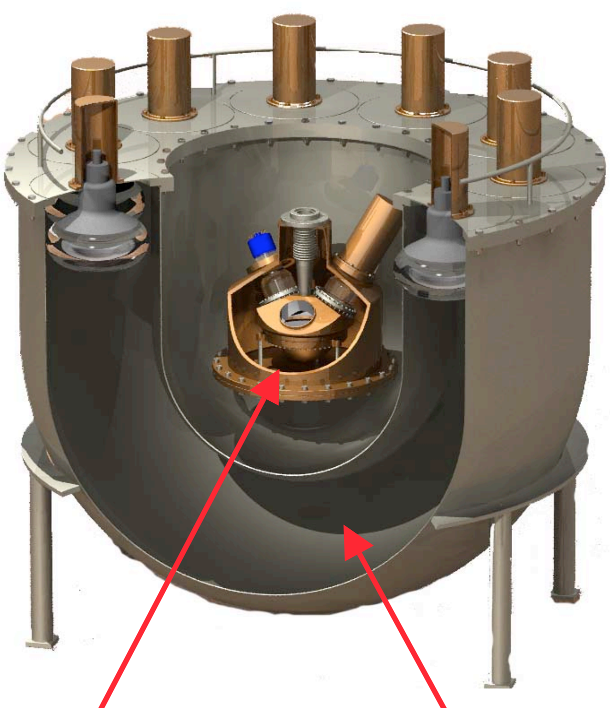


Courtesy of T. Shutt

B.A.Dolgoshein, V.N. Lebedenko, B.U. Rodionov, JETP Lett. 11 (1970) 513.

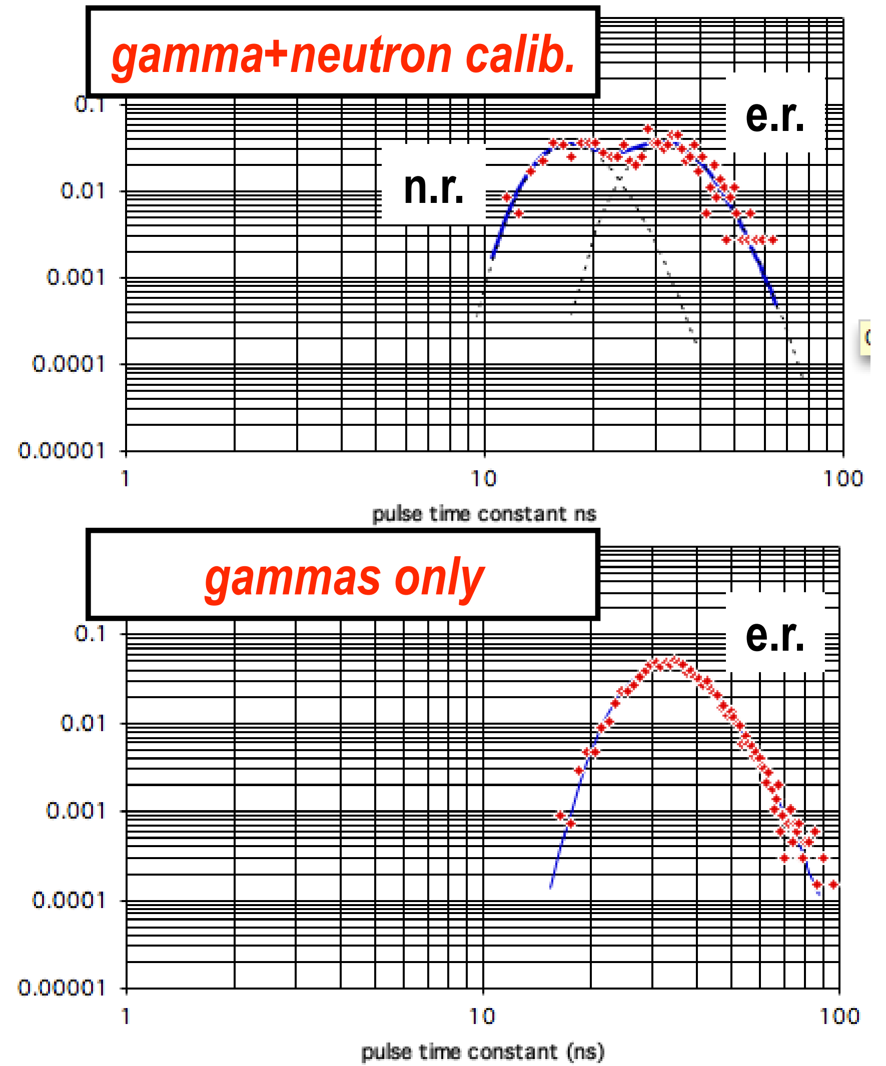
UK Collaboration: Zeplin I

- Single-phase detector
  - Measure primary scintillation
  - Pulse shape discrimination



5kg LXe target (3.1kg fid)
3 PMTs
Cu construction
Polycold cryogen cooling

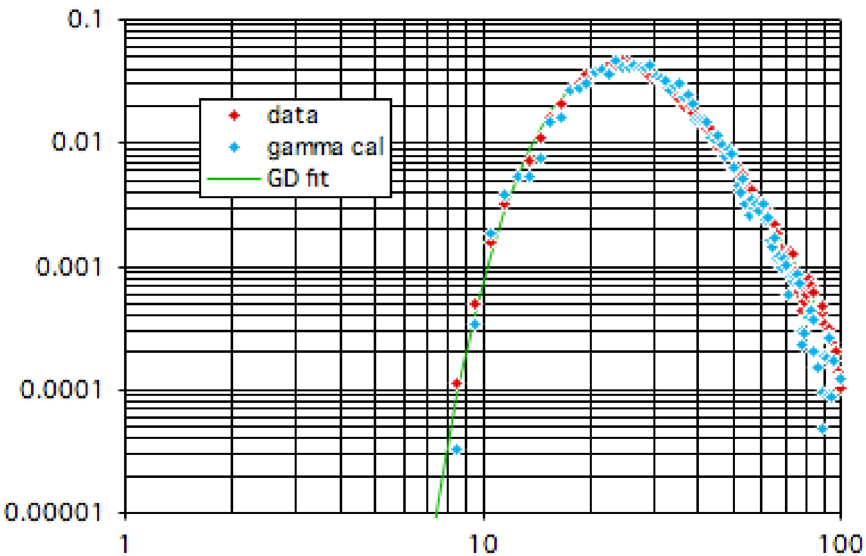
1 tonne Compton veto



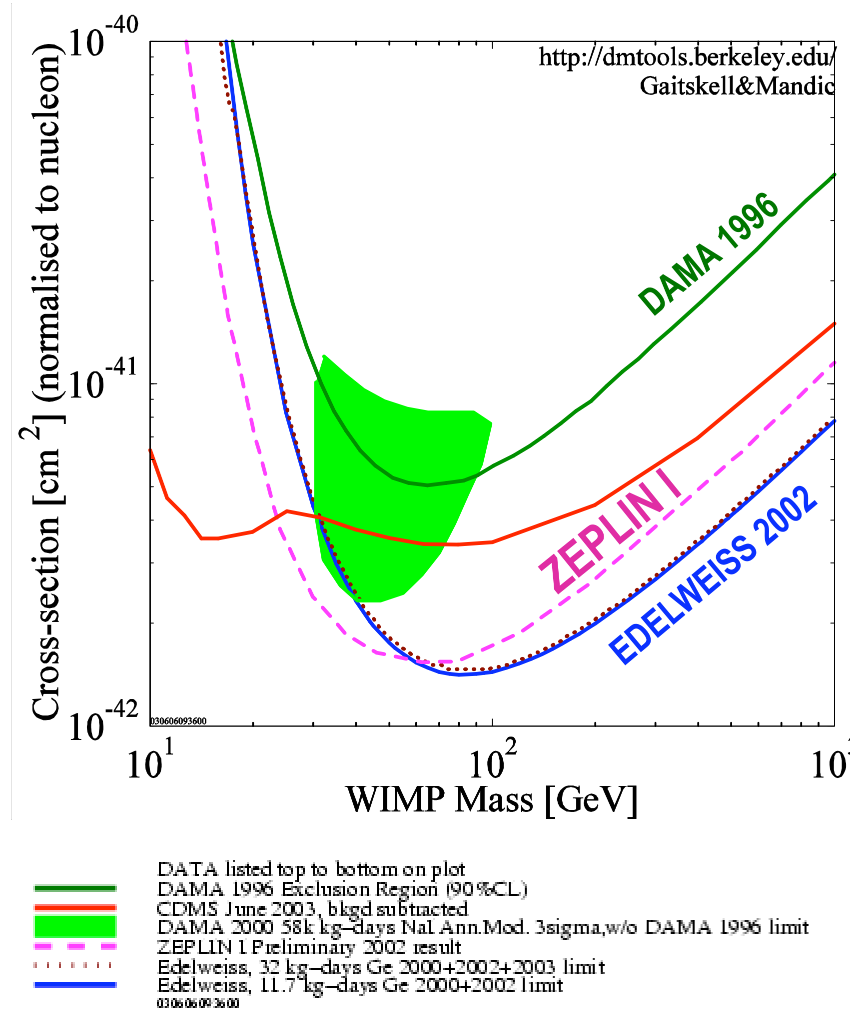
Pulse shape

Zeplin I: Best limit on Xenon target

- **230 kg-days in 3.1-kg fiducial mass**
  - Gamma calibration data from contemporaneous veto events
  - Systematics dominated — no *in situ* neutron calibration
    - Trouble recondensing target

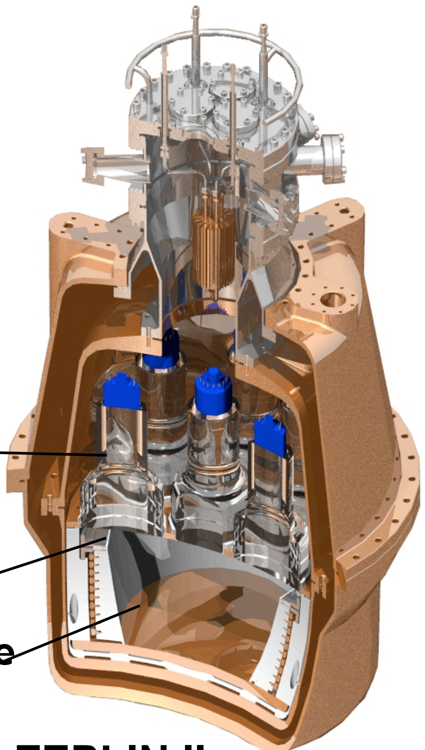


Pulse shape



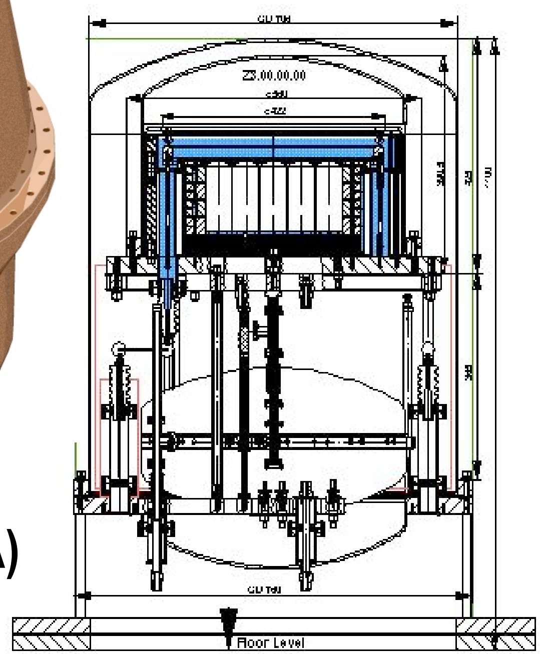
Astroparticle Physics 23 (2005) 444–462

Technology demonstration 10 kg → 100 kg → Ton scale



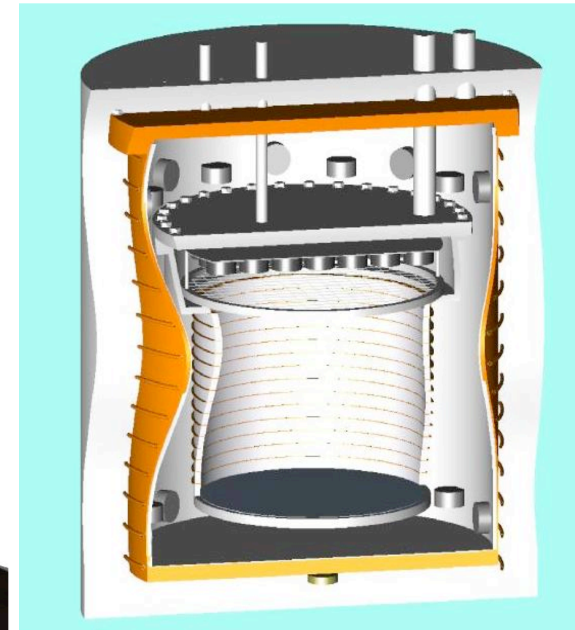
ZEPLIN II

(UK+UCLA)



ZEPLIN III

‘XENON’ Collaboration
(Columbia et al)

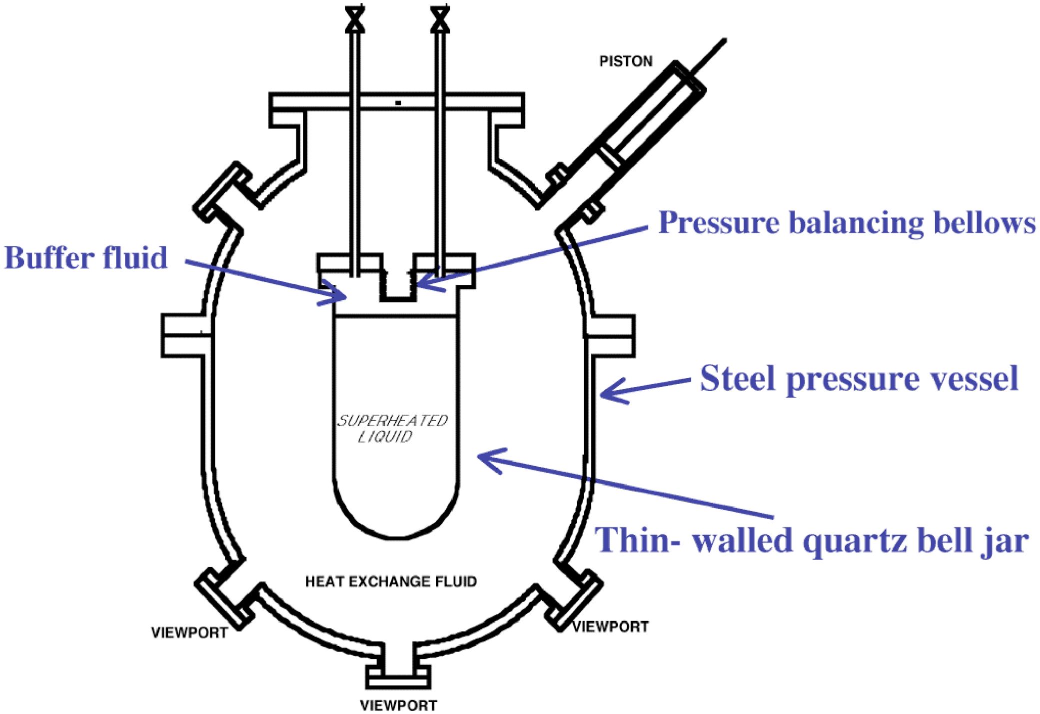


ZEPLIN MAX – 1-Ton

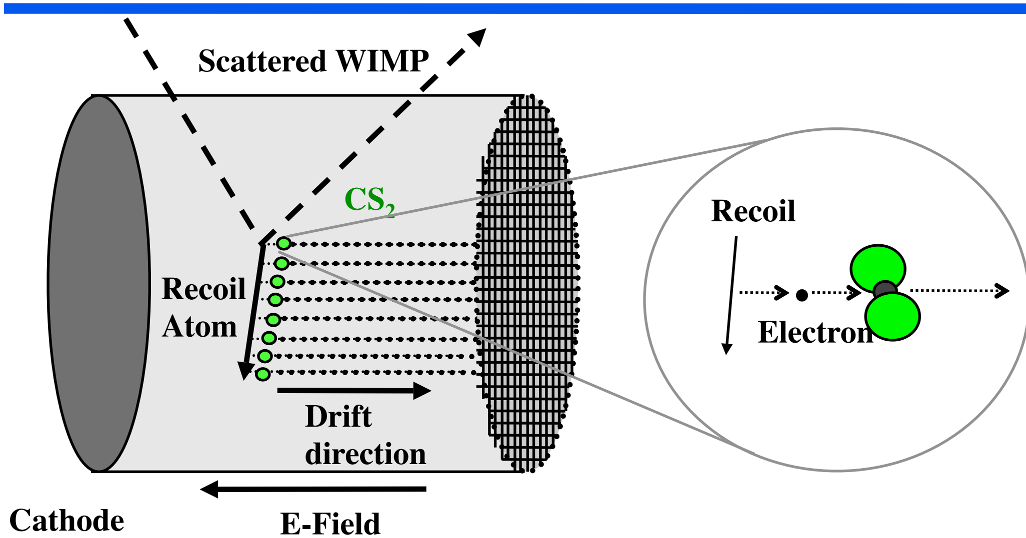
+DEAP (LAr)
+CLEAN (LNe)
+WARP (LAr)
+XMASS (LXe)

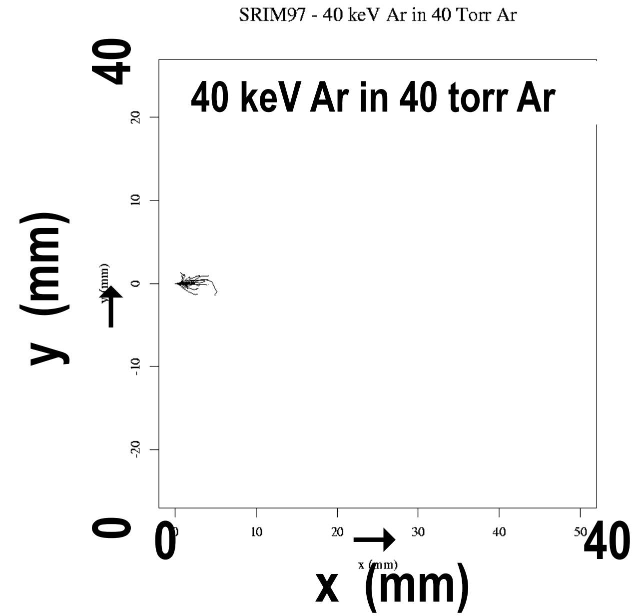
Bubble Chamber Revival

- 2-kg CF_3I Bubble Chamber – Chicago group (Collar, Sonnenschien, Crisler)
- Tune thermodynamic parameters
  - Insensitive to min. ionizing and low-energy electron recoils
  - Stability (time between events) consistent with laboratory neutron background



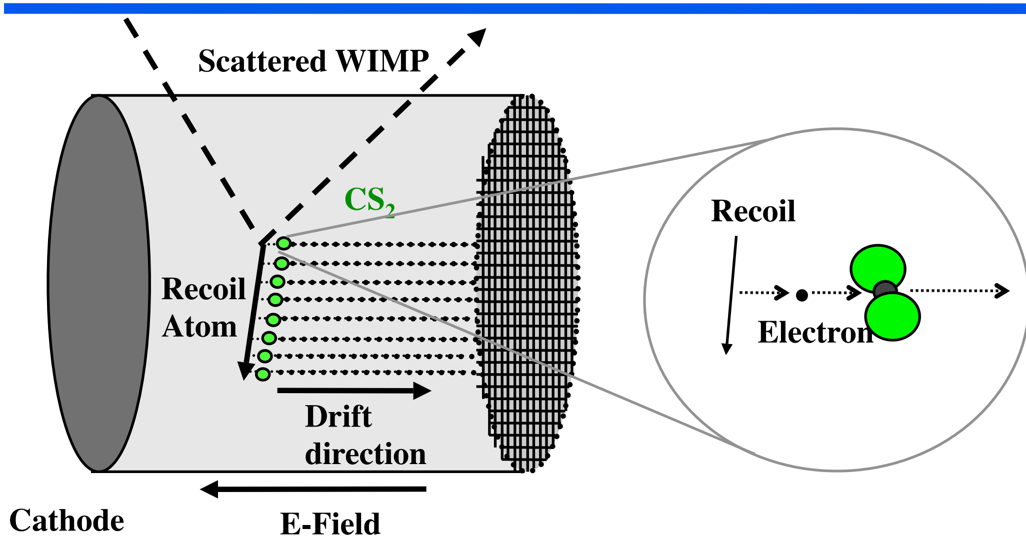
Galactic origin: Directional signal & DRIFT

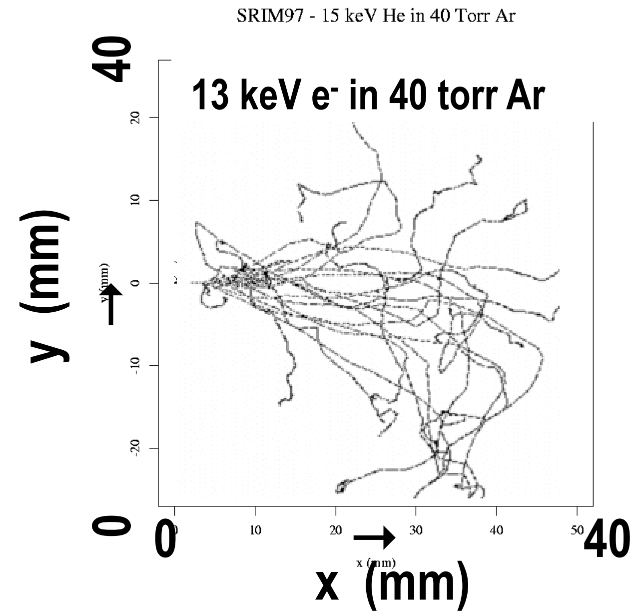




- Sensitive to direction of recoiling nucleus
  - Diurnal modulation signal – galactic origin of signal
- Drift negative ions in TPC (J. Martoff, Temple U.)
  - No magnetic field required
  - Reduced diffusion
- Electron recoils rejected via dE/dx
- DRIFT I: Proof of principle
- DRIFT II 1-kg modules
  - Full demonstration
- *Challenge is MASS: how big is needed for ~100 events?*

Galactic origin: Directional signal & DRIFT





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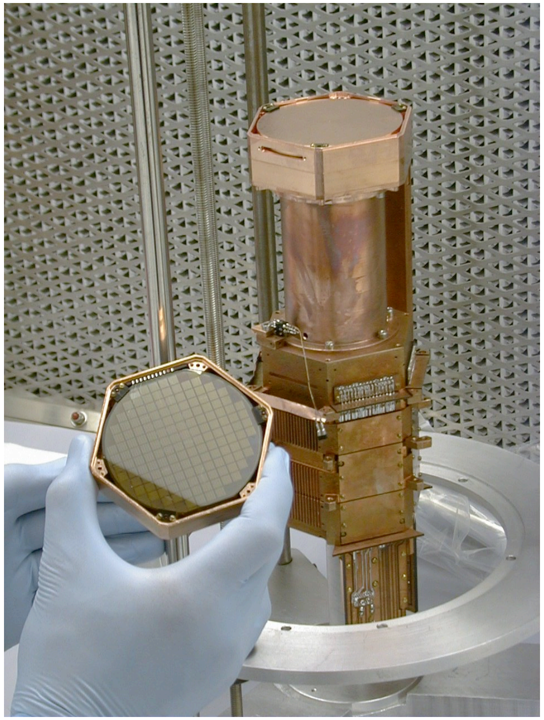
Summary

- Dark matter remains a fundamental mystery
  - Central role in cosmology, but we don't yet know its nature
  - Possible solution lies in new fundamental particle physics
    - Direct detection of DM ⇔ Frontier HEP at accelerators
    - Explore interesting SUSY region on similar time scale
    - Potential to provide key info to ILC
  - An essential aspect to finding a concordant model:
    - dark matter in the laboratory ≠ dark matter in the halo!
    - measurements needed on both frontiers
      - particle mass
      - particle lifetime
      - relic density
  - Indirect detection: astrophysical signal from annihilation products
- Significant recent advances in sensitivity
  - New technologies have come online
  - Broad R&D enterprise
  - Next 5-10 years looks very exciting!

Thank you…



...on the web at: cdms.case.edu